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PART II

HISTORICAL GEOLOGY

Restoration of an ancient herbivorous reptile, the "duck-bill" dinosaur ***Trachodon annectens***, which dwelt in the fresh-water marshes of Montana and Wyoming towards the close of Cretaceous time. (After Osborn, from a drawing by Charles R. Knight.)

A COMPREHENSIVE GEOLOGY

BY

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PART II

HISTORICAL GEOLOGY

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PREFACE

THE treatment of the subject matter of Historical Geology employed in the present volume is a somewhat radical departure from that usually followed in textbooks of this class. I have placed the emphasis upon stratigraphic development rather than biologic, because I believe that the former is more readily grasped by the student and will have greater interest for him. The biological aspect has not been neglected, but its treatment has been segregated mainly in special chapters. Thus there is an introductory chapter in which the classification, structural characters, and life habits of plants and animals are considered, with illustrations drawn largely from modern types. A separate chapter treats of the life of the Palæozoic after the Palæozoic systems have been discussed. Here the endeavor has been to present the development of life during the Palæozoic in a sequential manner, the classes being discussed separately. A similar treatment is accorded the life of the Mesozoic after the chapters on Mesozoic stratigraphy. The life of the Tertiary and that of the Quaternary are treated in separate chapters following the stratigraphic discussion.

The chapters dealing with the systems have generally been arranged according to a uniform plan. After a brief historical consideration and generally a table of the subdivisions, several characteristic sections are described and illustrated with sections and typical figures of a few fossils. Then the stratigraphic development in America and Europe is discussed and illustrated with ideal sections and palæogeographic maps, to show the relationship of the formations at the time of formation and the geographic conditions which determined their distribution and character. Some teachers will find that the fossils here given are sufficient for the needs of the elementary student, while for those desiring to give a more extended survey of the index fossils of each system, the section on the life of the period, with its greater abundance of illustrations, will serve as a text.

The illustrations have been drawn from many sources. Photographs of typical New York State localities were loaned by the New York State Museum, Dr. John M. Clark, Director. Others were obtained from the United States Geological Survey, Dr. George Otis Smith, Director. The *Popular Science Monthly* also loaned a number of photographs, while a large number of photographs of the skeletons and restorations of reptiles and mammals were obtained from the American Museum of Natural History. To these institutions and the gentlemen who represent them, my best thanks are due. Other photographs have been received from individuals as acknowledged in their proper places. Illustrations of fossils and a number of sections and other illustrations were taken from various books, the principal ones being indicated by letters as follows: Kayser's *Geologische Formationskunde* (K); Haug's *Traité de Géologie* (Hg); Steinmann's *Einführung in die Paläontologie* (S); Zittel, *Grundzüge der Paläontologie* (Z); Grabau and Shimer's *North American Index Fossils* (I. F.). From the latter work the original sources of illustrations of the fossils can be obtained. The publications of the United States Geological Survey, the Geological Survey of New York, and others have been freely drawn upon for illustrations. Sections from my field notes both in America and Europe have been introduced whenever such sections seemed called for to illustrate the text. Original illustrations have been prepared by Miss Mary Welleck, and in the preparation of the sections and the palæogeographic maps I have had the efficient assistance of Miss Welleck and Mrs. M. Tucker.

In preparing the text for the press, I have again had the able assistance of my former student, Miss Mary Welleck, who also assisted in the proof reading. The entire proof was also read by my friend, Mr. Ernest Welleck, of the editorial staff of the *Popular Science Monthly*. To these friends my best thanks are given. To Dr. Marjorie O'Connell I am especially indebted for careful and efficient work on the proof and illustrations. Finally to all colleagues who by criticism or otherwise have helped me to eliminate errors and clarify the presentation of the great subject of Earth Evolution, I herewith tender my most sincere thanks.

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CHAPTER XXIV

CHRONOLOGICAL CLASSIFICATION OF THE ROCKS OF THE EARTH'S CRUST

A CHRONOLOGICAL classification of rocks differs from a lithological one, in that it takes account primarily of their age relations, and considers their lithic character of secondary importance.

UNITS OF CHRONOLOGICAL CLASSIFICATION

Formations

The unit of chronological classification of rocks is the *formation*, a term of somewhat variable applicability and first proposed in the middle of the eighteenth century by Füchsel. A formation may be either igneous or sedimentary. In the latter case it may include either a single stratum or several strata. All the members of a formation, however, were formed during a limited time period in the history of the earth. Ordinarily a formation is delimited on a lithological basis, and it is made to include between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied, as, for example, a rapid alternation of shale and limestone strata. Such formations are given local names, the name selected being that of a town or of a river or other natural object with which the formation is associated.

Formations are limited in horizontal extent, because the conditions favoring their deposition were local and varied from place to place. Thus two formations of different lithological character will be formed at the same time in two distant localities. If it can be determined that these two formations are exact equivalents, the same name may be applied to both, irrespective of their lithology. This determination, however, is not generally possible, especially during the earlier stages of the study of a region, and thus the two formations will be given separate names.

It often happens that what appears to be a single lithological unit, such as a shale, or a series of limestone beds, turns out on closer study, especially of its organic remains, to include two or more distinct formations. Then the old name of the compound formation has to be dropped and new names must be given to the several divisions thus delimited, or the old name may be restricted to a part of the compound series.

Systems of Formations

Formations which have a certain unity of character, especially in the organic remains which they contain, are grouped together to form geological *systems*. The establishment of geological systems has been gradual in the history of the science, new ones being added from time to time to those recognized before. Such new systems were in some cases made by the division of the older ones, while in others it was recognized that two systems, found to be in close juxtaposition in one region, were separated, at another locality, by a system not previously recognized. In general, the upper and lower limits of geological systems are fairly well defined in most countries, but in some sections the limitation may not be so readily determinable, and systems which appear to be a unit in one region may, in another, show characters which would suggest their subdivision into two or more systems. Since the classification has been one of historic growth, it is desirable briefly to outline its development.

History of Development of Chronological Classification

Classification of Primary Divisions. — The earlier geologists had no understanding of the real time relations of the rocks of the earth's crust, nor did they realize that there was such a thing as a successive series of rock formations which could be recognized as the same if found in other localities. It was not until the eighteenth century that the idea of the successive origin of rock formations was grasped and that chronological or stratigraphic geology had its inception. This took place almost simultaneously in the different European countries where geology was cultivated. In England, we are told, John Strachey was the first to recognize the succession of formations in the coal-fields, and that although these strata were inclined, they were succeeded by nearly horizontal formations ranging from the Red Marl (Triassic) to the Chalk. This view was published in 1719 and 1725. In Italy, Giovanni Arduino (1713–1795) classified the rocks of the north of Italy into (*a*) *Primitive*, comprising the schists and other rocks, which form the core of the mountains; (*b*) *Secondary*, comprising the stratified *fossiliferous* rocks which overlie these; (*c*) *Tertiary*, the disintegrated sand and other loose material which often contains the remains of land animals and plants; and (*d*) *Volcanic*, rocks which consist of the lavas and tuffs produced by repeated volcanic eruption.

In Germany, the chronological relation of the stratified to the older rocks and to the unconsolidated material overlying them was independently recognized by Johann Gottlob Lehman, whose studies were published in 1756 and Georg Christian Füchsel, whose works appeared in 1762 and 1773. Lehman's studies were carried on in the Harz Mountains and in the Erzgebirge, that range of mineral-bearing hills between Saxony and Bohemia which has played such an important part in the development of both mining and geological thought. In the cores of both these mountain masses, he recognized the older or *Primitive* rocks (*Urgebirge*), which were the first to be formed in the making of the earth. In many exposures in the vicinity of Dresden and elsewhere in the mountains on the Bohemian border, these old rocks, consisting of porphyries, of granites, inclined schists, etc., are abruptly covered by horizontal strata, beginning generally with conglomerates, which are succeeded by sandstones, followed by limestones, the latter often with many fossils (Fig. 735). All of these belong to the system now called Cretaceous. They constituted Lehman's second division, and he designated them by the current miner's term of *Flötzgebirge*, which signifies horizontally-lying rocks. He recognized that they were formed as successive layers by sedimentation in water which once covered the region, and that they succeeded one another in a definite and recognizable order within the district. Overlying these stratified deposits were the unconsolidated series of gravels, sands, and loess which were designated

Alluvium (*Angeschwemmtgebirge*), and regarded as the deposits formed by the Noachian Deluge. These we now know to be, in part at least, of glacial origin. The general relationships of these formations are shown in the following diagram (Fig. 735). A view

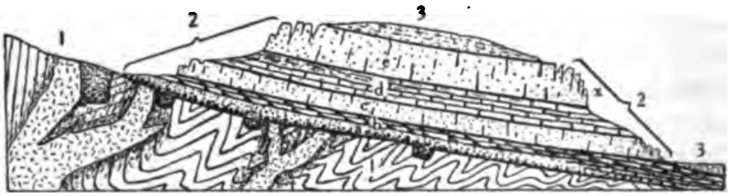

FIG. 735. — Section in the "Saxon Switzerland" near Pirna, with the valley of the Elbe on the right, showing the relationships of the formations in the region studied by Werner. 1. *Urgebirge*, or *Primary rocks*. Gneiss, schist, syenite, etc., ending above in an unweathered erosion surface in which pot-hole-like depressions are frequently found. 2. *Flötzgebirge*, or *Secondary rocks*. Cretaceous. (*2a*, *b*, Cenomanian; *2c–e*, Turonian.) *2a*. Basal conglomerate and Lower "Quader" sandstone, replaced laterally by Pläner (see Fig. 737 *a*). *2b*. *Carinatus* Pläner. Thin-bedded limestones with *Ostrea carinata*. *2c*. Middle Quader sandstone replaced near Dresden by *Labiatus* Pläner, or thin limestone, with *Inoceramus labiatus* (Fig. 1699 *a*). *2d*. Thin-bedded limestones and marls with *Inoceramus brongniarti* (Fig. 1740) (*Brongniarti* Pläner). *2e*. Upper Quader sandstone, forming picturesque cliffs above the Elbe River (see Fig. 736). 3. *Angeschwemmtgebirge* or *Alluvium*. Glacial deposits and loess. (Original.)

of the cliff of Secondary sandstone (*Flötzgebirge*) exposed on the Elbe is shown in Fig. 736. The rock is strongly jointed, and disintegration and deflation have produced picturesque pillars, buttresses, and other erosion forms which simulate an alpine landscape and have suggested the name Saxon-Bohemian-Switzerland (*Sächsish-Böhmische-Schweiz*) for the region. Two other sections, showing the relationships of the formations in the vicinity, are given in Figs. 737 *a*, *b*.

Füchsel's studies were made in the hills of the Thuringian Forest, the core of which consists of ancient rocks, chiefly crystalline schist and granites. On their flanks lies a great series of stratified rocks with a gentle inclination, ranging from the coal-bearing beds, or from the Permian, to the Muschelkalk or the Keuper Marls (Triassic). He considered that these inclined strata were originally deposited in a horizontal manner and that their present position was due to disturbance. He also held that the formation of these deposits took place during a definite period in the history of the

FIG. 736. — Cliff of Secondary sandstone (Quader sandstone) above the Elbe River, near the Saxon-Bohemian border (Bastei). See section Fig. 735 at x.

earth and that similar formations were deposited elsewhere during the same period. Overlying the Muschelkalk or the Keuper Marl in the Thuringian region is the unconsolidated material spoken of as Alluvium, and this was regarded by Füchsel as the record of the Great Deluge. The following section (Fig. 738) shows this arrangement of the strata. Thus it will be seen that although Lehman and Füchsel recognized the same general succession of ancient rocks, of Flötz formations (Secondary), and of Alluvium, the Flötz formations of the two were not the same, those of Füchsel's region being older (Permian and Triassic) than those of Saxony (Cretaceous), which, in turn, are wanting in the Thuringian region.

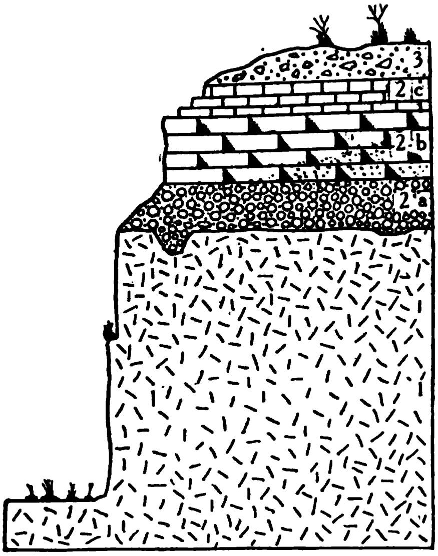

FIG. 737 *a*. — Section of the rocks in the Plauen Gorge (Plauenscher Grund) near Dresden, Saxony, illustrating the relationships of the formations studied by Werner. (From the author's field studies.) 1. *Urgebirge*, or *Primary rocks*. Syenite. 2. *Flötzgebirge*, or *Secondary rocks*. Cretaceous. 2*a*. Basal conglomerate 1½ meters thick, containing numerous well-rounded boulders of the syenite, and resting upon an unweathered erosion surface of the latter, occasionally filling ancient pot-hole-like hollows. The sandy matrix of the boulder conglomerate is highly fossiliferous (Cenomanian). 2*b*. Thin-bedded limestone (Pläner), with *Ostrea carinata* (*Carinatus* Pläner, Cenomanian). 2*c*. Similar beds with *Inoceramus labiatus* (*Labiatus* Pläner, Turonian). 2*b* and 2*c* have a combined thickness of 3 meters. 3. *Angeschwemmtgebirge* or *Alluvium* (boulder clay, loess, etc., Quaternary). (Original.)

There is, moreover, no agreement in the use of these terms by the pioneer German and Italian stratigraphers. The "Primitive" rocks of north Italy often inclose metamorphosed Mesozoic formations, which are of the age of the Secondary rocks of Germany. The "Secondary" of Arduino includes rocks now placed in the Tertiary, and his Tertiary corresponded more nearly to the Alluvium or Quaternary series of German and French geologists.

It was, however, Abraham Gottlob Werner, professor of mining and mineralogy in the Mining Academy of Freiburg in Saxony,

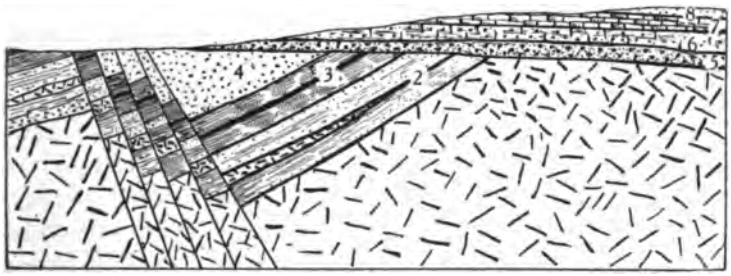

FIG. 737 *b*. — Section near Dresden, showing how, in places, Palæozoic (Permian 2–4) strata appear beneath the Secondary or Mesozoic (Cretaceous 5–7) beds. (From the author's field notebook.) 1, Primary rock (syenite); 2, lower Rothliegendes, basal sands and clays, gray sandstone, shales and coal with an intruded bed of hornblende porphyry; 3, middle Rothliegendes, red shales, etc., with a bed of coal; 4, upper Rothliegendes, conglomerates, sands, and tuffs; 5, basal conglomerate; 6, sandstones, coals, limestones, and variegated shales with *Ostrea carinata* (*Carinatus* Pläner); 7, thin-bedded limestone with *Inoceramus labiatus* (*Labiatus* Pläner); 8, Alluvium. (Original.)

who made this idea of geological succession the foundation of the science of geology as then understood. This, as we have seen, was accomplished chiefly through his teachings and the work of

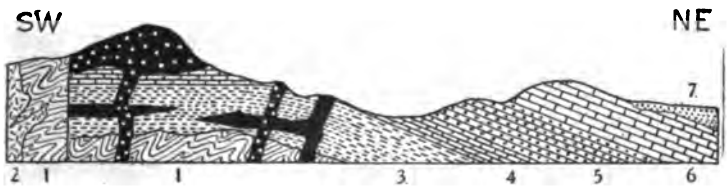

FIG. 738. — Section in the Thuringian Mountains of Germany, the region studied by Lehman, extending from the Inselberg (on the left) northeastward to Waltershausen. 1, 2, *Urgebirge* or *Primary rocks* (1, crystalline schist, 2, intrusive granite); 3–6, *Flötzgebirge* or *Secondary rocks* (3, Rothliegendes, tuffs and sandstones of Permian age; 4, Zechstein, Permian limestone; 5, Buntsandstein, Lower Triassic; 6, Muschelkalk, Middle Triassic. The Upper Triassic Keuper occurs in other sections). 7, *Alluvium*. Intruded porphyries in black, the younger with white dots. Note that the Secondary or Flötz of this region is older than that of the Saxon-Bohemian region, comprising Triassic and late Palæozoic (Permian). (Original.)

his pupils. Werner promulgated the idea of universal formations based on the succession found in his home region of Saxony, and these he regarded as extending over the entire globe. The first formed or Primitive rocks (*Urgebirge*), which he regarded as chemical precipitates from the primordial ocean, included granite, gneiss, mica schists, slates, etc. Upon these rest the Secondary rocks, — sandstones, limestones, rock-salt, etc., and upon these the alluvial deposits. He also recognized an older series of rocks consisting of graywackes, slates, and limestones, between the Primitive and the Secondary series, and these he called *Transition rocks*, holding them to have been deposited during the passage or transition of the earth from its chaotic to its habitable state. In these rocks are found the oldest organic remains and they mark the change from chemical to mechanical deposition. They comprise a part of what we now call the Palæozoic series.

At the beginning of the nineteenth century the rocks of the Paris Basin were studied by Cuvier and Brongniart, who found that between the chalk beds, which belonged to the Secondary division of the German geologists, and the Alluvium, there was a great series of clays, sandstones, limestones, marls, and gypsum beds, partly of marine and partly of fresh-water origin, with shells and the remains of vertebrates unlike any found either above or below. They also noted a remarkable constancy in the succession of the formations, and further found that these beds could be recognized from point to point by the fossils which they contained. Thus a new series of strata was recognized between the Secondary and the Alluvium, one not found in the region studied by the German geologists, though well developed elsewhere in Germany and in the adjoining countries. To these the name Tertiary was applied, though they represent only a part of the formations now included in this series. In much more recent times, the term *Quaternary series* was applied to the unconsolidated (glacial, etc.) material which was found to lie upon the Tertiaries in one region and upon the Secondary rocks in another.

Finally, studies in North America and in Scandinavia led to a subdivision of the Primitive rocks into the Archæan at the bottom and the Algonkian above these, and later to still more detailed subdivisions of the oldest rocks (see the Table, on page 20). Up to this point, then, the rocks of the earth's crust had become subdivided into a number of groups, representing the successive time periods in which they were formed. These, with their modern equivalents, are as follows:

CHAPTER XXV

MAPPING AND CORRELATION OF GEOLOGICAL FORMATIONS

Geological Maps and Sections

The geological formations of a country and the structure of these formations are recorded upon a geological map and in geological sections.

Geological Maps

Types of Geological Maps. — Geological maps may be of two types — (1) showing only the outcrops of rocks with indication of the dips and strikes and such other structures as faults, etc., and (2) the complete or interpolated geological map in which the formations are drawn continuously, even over regions where they do not outcrop. This is the more common type of map, and the more serviceable, for though it always contains an element of error, proportionate in magnitude to the intricacy of the structure of the region, it also presents a comprehensive view of the geology of the district, such as one could not obtain without much study from the outcrop map alone. Two varieties of this type of map are again recognized. The first takes no account of the surface soil, drift, or vegetation, but represents the rock structure as it probably would appear if all the mantling material were removed so that only the rock surface remained. This is the usual method of representation adopted by American geologists, as a glance at almost any American map will show. While more easily read than any other kind of map, this type gives no indication of the actual outcrops of the rocks, and the geologist using such a map in the field finds it frequently very tedious and time-consuming to locate the exposures. This is obviated by the second type of map, where the geological formations are colored throughout, but the surface material is indicated by an over-coloring which leaves the actual outcrop areas untouched. This is a common method of representation adopted by European geologists, as a glance at the Geological Map of Ireland (Bartholomew) or the International Geological Map of Europe will show. It must be acknowledged that the patchwork thus produced renders the reading of such a map often difficult, unless the over-color is very faint. For the field explorer, however, this type of map has obvious advantages.

The complete map, of course, embodies the geology of the country as interpreted by the maker of the map (the geologist), and it is based upon the outcrop map, which is the type constructed in the field. Outcrop maps are seldom published as such unless the structure of the country is too intricate and the exposures too few to warrant interpolation between the outcrop areas.

Caution Necessary in Reading the Geological Map. — One of the most common errors made by the beginner in reading a geological map is to assume that the belts of color which are shown upon it represent so many belts of rock formation, the areal limits of which are bounded by the limits of the color bands. In other words, the boundaries of the geological formations are assumed as extending vertically downward into the earth, a condition which is seldom realized in nature, and is far from correct when the rock formations are stratified and only moderately inclined. In such a case, the color band represents merely the portion of the formation projecting from beneath the next younger series, as the exposed part of a shingle on a roof or the side of a house represents only a portion of the whole shingle, the remainder being covered. In general, unless the map represents a very large or much disturbed area, each formation may be assumed to extend under the higher ones throughout the area represented, unless, indeed, the strata actually stand in a vertical position. The true relationships of the formations are represented upon the geological cross-section.

Scale and Detail of Geological Maps. — The scale of the geological map depends upon the area of the country represented and the size of the map. In general, the smaller the area mapped and the larger the map, the larger will be the scale, and the more detail will be represented. In extremely complicated districts or regions with many thin formations, large scale maps are required to represent these features.

The principal types of maps in use, from the point of view of detail, are the *system map* and the *formation map*. An intermediate type, in which the larger subdivisions of the systems or the groups of formations are shown, is also made.

The System Map. — The system map represents only the outcrops of the several geological systems as they would appear if the mantling of loose material and vegetation were removed. In general, a definite color or shade is used for each system by all countries producing these maps, though such a color scheme is not strictly adhered to. Thus purple is, as a rule, used for the Triassic system, blue for the Jurassic, green for the Cretaceous, and various shades of yellow and orange for the Tertiary systems. There is less uniformity in the use of color for the Palæozoic systems. When the geology is not too complex, it may be represented satisfactorily by a system of patterns only, printed in black (Fig. 742). The geological map of North America published by the United States Geological Survey is a typical example of a system map. Greater detail is represented by the International Geological Map of Europe. Here most of the systems are subdivided into their lower, middle, and upper portions, while in some cases even greater detail is shown. This is usually accomplished by the use of various shades of the systemic colors, and further by the addition of numbers and letters to aid in identification (see below). The large geological map of New York state shows still further detail; in some cases formations are represented, in others, groups of formations such as the Hamilton group, Helderberg group, etc.

The Formation Map. — In the folios of the Geological Atlas of the United States, published by the Federal Survey, and in the large scale map sheets issued by the New York State Survey, the formation is the unit of cartography. This, with few exceptions, is the most detailed type of geological map produced, though maps of even greater detail are made now and then for special areas. The formation, as defined for purposes of mapping, is of uniform lithologic character, or of uniform variability throughout, and is determined primarily on a lithic basis and secondarily on the basis of its contained fossils. Each formation is given a distinct name, but as formations vary in character from place to place, equivalent formations in adjoining or slightly distant map areas may receive distinct names. As an illustration of this may be taken two quadrangles or map sheets of Tennessee, — the Columbia and the McMinnville, — between which there lies an area equal to two map sheets only. Although formations of the same age occur in both, still the actual characters and names of the formations differ entirely in the two maps, with the exception of the Chattanooga black shale. In the following diagram (Fig. 749) the changes in a series of sediments from the shore seaward are shown in *A*, the

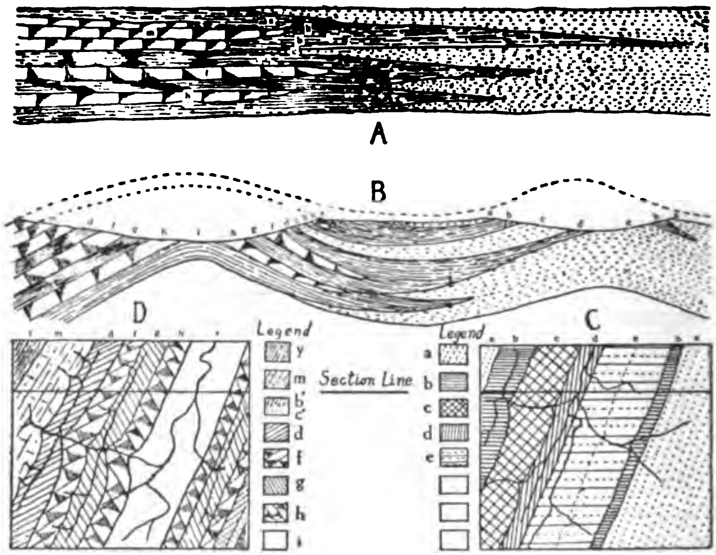

FIG. 749. — Relation of maps and sections. *A*, section showing variation of strata from shore seaward; *B*, the same section after folding and erosion; *C*, *D*, maps of the same region representing the two end quadrangles (separated by one quadrangle). These two maps have scarcely any formations in common, although the formations of one are representative of those of the other. (From *Principles of Stratigraphy.*)

outcrops after folding and erosion in *B*, and two maps of the eroded anticlines in *C* and *D*. These two maps have scarcely any formations in common.

Notation and Legend of Color Patterns. — In order that the geological map may be interpreted, it is necessary to place upon it a key to the color scheme. This is called the legend of the map and consists of small rectangles, each colored to correspond to one of the colors upon the map, and with the formation or system name placed opposite or under each. These rectangles are arranged in the order in which the formations (or systems) occur, the oldest generally at the bottom and the youngest at the top. In some cases, however, the order is reversed, as in that of the larger map sheets of New York state, where the older formations appear at the top of the map and the younger at the bottom. The legend is placed upon the side of the map to correspond with this arrangement.

In addition to the color, it is generally desirable to use some form of notation to avoid confusion between similar colors or patterns. On the geological map of North America, each system is given a number, the Quaternary being 1, the Cambrian 18, while higher numbers up to 24 are used for the pre-Cambrian and the igneous rocks. Special developments of some formations are designated by additional letters. On the folios of the Geological Atlas of the United States, letters are used, a capital for the system (*S* for Silurian, *D* for Devonian, etc.), and small letters for the formation name. Thus on the Hancock quadrangle, where five Silurian formations are represented, the notations are: *Sc*, Clinton Shale; *Smk*, McKenzie formation; *Stw*, Tonoloway limestone, etc., the *S* in each case indicating the Silurian age of the formation.

Geological Sections

Three types of geological sections are resorted to in order to depict the geology of a region. These are: (1) the natural cross-section, (2) the columnar section, and (3) the restored section.

The Cross-section. — If we could cut a deep trench in the surface of the country, one that might extend for thousands of feet in depth, we would get in the wall of such a trench an accurate picture of the character, thickness, relative position, and attitude of the strata composing that part of the country. The representation of this, from data obtained from surface outcrop and borings, is attempted in the construction of the natural cross-section, which, because of the limited information available, must of necessity contain many elements of error, though on the whole it may be a fairly accurate presentation of the actual conditions. Only in limited areas, where tunneling or excavations permit underground examination of the strata, and comparison with surface outcrops, can a section be constructed which approaches in accuracy the actual conditions. This is illustrated by the section of the Simplon Tunnel in the Alps (Fig. 525, p. 608, Pt. I). Nevertheless, cross-sections are a necessary part of geological representation, and in general the inaccuracies are of negligible quality.

The cross-section shows the profile of the country and the position and structure of the rocks as they are at the present time. The most satisfactory sections are drawn to the same horizontal and vertical scale, and such a section shows the true dips of the strata, together with their proportional thicknesses. Because of the great horizontal extent of most sections, however, it becomes necessary to enlarge the vertical scale, making it sometimes as much as five or ten times the horizontal. This of course greatly exaggerates the dips and the thicknesses of the strata, as well as the relief of the country. The following two sections (Fig. 750) illustrate the dif-

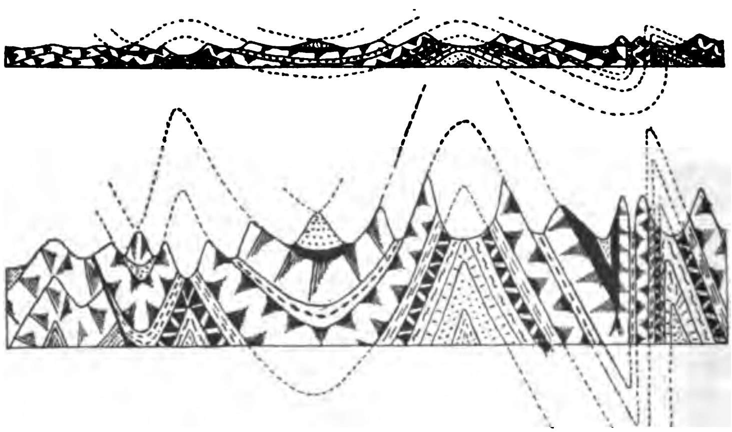

FIG. 750. — A geological section, drawn with horizontal and vertical scale alike (upper), and with vertical scale five times greater than the horizontal (lower). Note that the exaggeration of the vertical scale produces: 1, enormous exaggeration of topography; 2, increase in dip of strata, and fault planes and sharpening of folds, etc.; 3, increase in thickness of inclined and horizontal portions of strata, though the thickness of the vertical beds remains the same; 4, distortion of strata due to apparent variable thickness, which differs from the actual.

ference, the first being drawn to true scale, *i.e.* horizontal and vertical scale alike, while the second represents the same region with the vertical scale enlarged five times.

Columnar Section. — If in a region of horizontal strata a deep shaft were sunk, the sides of this shaft would present a columnar section of the rocks penetrated. Drawn to scale, with the character of the rock represented by conventional signs and the various beds depicted in their proportional thicknesses, it forms an important record of the geological formations of that region. Only original structures such as cross-bedding, unconformities, and disconformities, are indicated in such a section, subsequent structures such as faults, folds, etc., being of necessity omitted, though intrusive rocks may be shown. Thus even in a region of highly disturbed strata, a columnar section may be constructed from the

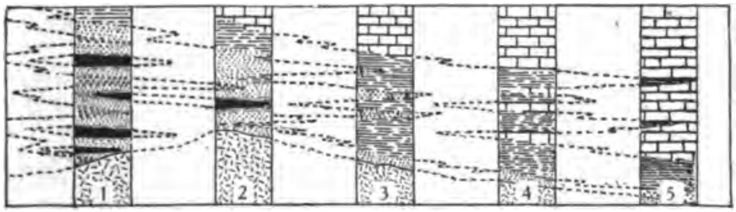

FIG. 751 *a*. — A series of five columnar sections drawn along a line at right angles to the old shore of the sea in which the strata were deposited.

ascertained thickness and normal succession of the strata. But such a section gives no indication of the complexity of structure of the region.

Columnar sections of different regions but of formations of the same geological age, and drawn to the same scale, are very instructive as showing the variation in the character and thickness of the rocks from place to place. They form a necessary basis for all generalizations of a broader nature. (See Fig. 751 *a*.)

Restored Sections. — By this term sections are designated which aim to present the conditions as they existed during the period of

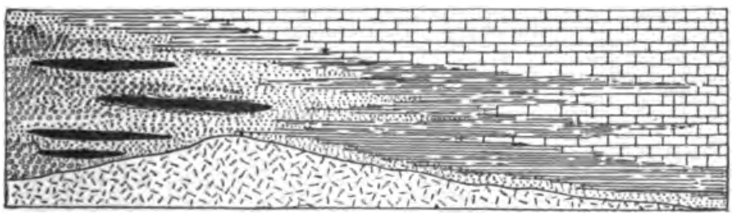

FIG. 751 *b*. — A restored section made by combining the data furnished by the five columnar sections. This represents conditions which existed before disturbances and erosion had affected the region.

formation of the strata in question. They represent, indeed, a restoration of a cross-section of the region at that period. As such, they ignore all subsequent disturbances, as well as the erosion which the country has suffered since the deposition of the strata. They may show the relative position of the land and sea, the overlaps of the strata, their horizontal changes in character and their vertical succession. Such sections are built up from a series of columnar sections distributed along the line on which the restored section is made. The preceding diagram (Fig. 751 *b*) shows such a restoration from a series of columnar sections.

Stratigraphic and Topographic Attitude of Formations

When the strata of a region are horizontal, the stratigraphically higher (younger) formations will also be the higher formations in a topographical sense. Thus in eastern New York, the Catskill is the highest (or youngest) of the formations of the Devonian system,

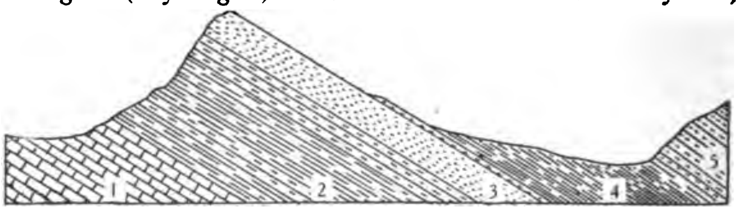

FIG. 752. — A cross-section of a uniclinal mountain such as Clinch Mt., Virginia, showing the relationship of stratigraphic horizons to topography, Formation 1 is the oldest or lowest, 5 the youngest or highest stratigraphically. Note that the outcrop of formation 3 is higher *topographically* than that of 4, but *stratigraphically*, or in the order of deposition, 3 is lower than 4. Thus formation 3 is spoken of as representing a lower horizon than formation 4. (In the Appalachian Mountains the formations represented are: 1, Lower and Middle Ordovician limestones; 2, Upper Ordovician shales and sandstones; 3, Silurian sandstones; 4, Devonian black shales; 5, Upper Devonian and Mississippian shales and sandstones.)

and it also forms the highest hills on the western bank of the Hudson. In regions of inclined strata, however, a higher (younger) stratigraphic division may crop out at a much lower topographic level than a lower or older formation. This is shown repeatedly in the Appalachian Mountains, where some of the valleys are underlain by strata much higher in the stratigraphic scale than those forming the mountains, as shown in the preceding diagram. Here, of course, the higher strata (stratigraphically) formerly extended over the mountain remnant still present, having been removed by erosion except in the valley bottoms (the syncline) (Fig. 752).

CORRELATION

It is not enough to determine the succession of formations of a region, their lithologic character and fossil content, and the structures subsequently developed, but their relative position in the geological series as a whole must also be ascertained. For this purpose it is first of all necessary to have a standard or type section with which sections of other regions may be compared. The identification of the stratigraphic position of the formations of a region with respect to those of the type section is termed *correlation* and is an important part of geological investigation.

Type Sections. — Theoretically, the region in which the geological formations of a series or system were first studied and their succession, details of character, and organic contents determined, becomes the type or standard section with which all others are compared. Thus the higher deposits of the Paris Basin become the type for the Eocene, and all deposits of this system in other regions are correlated with this standard. This principle is, however, not generally applied, except perhaps for the country in which such a section occurs. Thus while the west of England (Shropshire) and the Welsh region are the standard of the Silurian for Great Britain, a much better section for comparison is found in the Baltic region on the one hand (Island of Gotland), and in the region south and west of Lake Ontario on the other. Partly on this account many European geologists prefer the name Gotlandian for this system, while in America the name Ontaric system has been used in place of Silurian. The Devonian rocks of Devonshire, southwest England, form, on the whole, a much less satisfactory section for comparison than do those of the Rhine and other parts of western Germany, and correlation is more commonly made by European geologists with the west German succession than with that of southern England. The Triassic rocks of Germany are also very unsatisfactory as a standard section, though in a broad way correlation with the threefold division of that region is made. A much more perfect section and one that is wholly marine is found in the Alps, and this serves as the more usual standard.

In North America, the Palæozoic formations were first studied in detail in the state of New York, and the New York Series has become by common consent the standard of comparison for North America, and might also serve in some respects as the standard for other parts of the world as well. Nevertheless, the Cambrian is more fully developed in western North America and upon the northern Atlantic coast, and for detailed comparison these sections are used. Again, the Ordovician is more fully developed in the southern states, and the Silurian in Michigan and adjoining portions of Canada and Ohio. For the Devonian, the New York section is undoubtedly the best standard of comparison in America, but the higher Palæozoic formations are only sparingly represented. The Mississippi Valley section serves as the standard of comparison for the American Mississippian, though some divisions are more fully developed elsewhere, notably in Tennessee. No complete standard of comparison for the American Carbonic and Permian has yet been determined, although the Kansas section serves this purpose for a large part of these systems. The American Triassic and Jurassic are compared with European standards, but the Comanchean and Cretaceous have local standards in southern and western North America, although comparison with the European standard (especially the French) is also resorted to. The marine Tertiary sections of America are most typically developed in the Gulf region, though correlations with the European standard are also made. For the non-marine Tertiaries, western North America furnishes good standards.

It is generally recognized that a knowledge of the character and succession of formations of the type section is a necessary preliminary for purposes of correlation, but since this involves a knowledge of much detail, workers in stratigraphy have generally limited their efforts to a definite portion of the geological column. The general student should aim to obtain a broad view of the character and succession of the several systems and the main physical conditions of the world at the time of their formation, together with a survey of the succession of the types of plant and animal life which existed upon the earth during the successive stages of its development, and from these facts he should learn to deduce some of the laws which have governed the evolution of the earth and its inhabitants.

Methods of Correlation

Continuity of Formations. — If a geological formation can be traced from the type region, with little or no interruption of exposures, to a region where the formations are still undetermined, this would serve as a satisfactory basis from which correlation of the formations of the new locality with the type section may start. Such formations have frequently been traced, but in most cases it has been found that the continuity is only apparent; for example, that a bed of sandstone of definite position in the series in one locality rises or falls in the series when traced from point to point. The same thing is true for other types of rock formations as well, though to a lesser degree than with sandstones.

Superposition. — The regular succession of formations of similar character, or the superposition of formations, has also been used, but again with frequent commission of error. Thus the sandstones which in many portions of North America were found to rest unconformably upon the old crystallines, were formerly unhesitatingly correlated with the Potsdam sandstone which overlies the crystalline rocks of the Adirondack Mountains. Now, however, it is known that the ages of these sandstones vary greatly, and that they represent merely basal sandstones of overlapping formations. (See Figs. 977 to 984.)

Disconformities and Unconformities. — In some respects great disconformities, especially those due to widespread retreatal movements of the sea followed by readvance (see p. 559, Pt. I), serve as a useful guide in correlation when it is remembered that the series is less complete than elsewhere in the region from which the sea withdrew first, and to which it returned last. We shall have occasion to call more especial attention to some of these disconformities when discussing the formations of the various systems. Unconformities serve to locate the larger breaks in the geological succession, and these can sometimes be used over extensive areas within certain limits, but it must be remembered that the formations next above the unconformity are not always the same in different localities.

Fossils. — Undoubtedly the safest and most reliable means for the correlation of formations with the type section is found in the organic remains, or fossils, which occur in the strata. This implies, of course, that the succession of organic remains in the strata of the type region has been fully ascertained. While certain precautions are necessary even here, especially when attempts at detailed correlations are made, this method is sufficiently exact for most purposes and serves all the requirements for the correlation of the geological systems in their occurrence the world over. We must, therefore, next turn our attention to this subject and note the manner of occurrence and the mode of preservation of organic remains, and gain, moreover, a general knowledge of the several types of organisms which have inhabited the earth since the first appearance of life.

CHAPTER XXVI

FOSSILS, THEIR NATURE AND MODE OF PRESERVATION

Definition

Fossils (from the Latin *fossilis*=something dug-up) are the remains of animals and plants, or the impressions, structures, etc., made by them, which are preserved in the rocks of the earth's crust. The term was formerly used, in a more general sense, for all natural materials dug from the ground, including metals, ores, and the like, but it has now been limited in the manner above stated. The term *petrifaction* is sometimes used for such remains, but all fossils are not petrified or turned into stone. As a classical example we may mention the bodies of mammoths and other extinct animals which have been preserved in the Arctic ice, with flesh, skin, and hair intact, and the bodies of human beings found occasionally in peat bogs, where they may have lain for a century. Many fossil shells, bones, and teeth found in the younger formations have experienced no perceptible change from their original condition, and certainly have not been petrified. On the other hand, most older fossils have been more or less impregnated with mineral matter and so became truly petrified.

There is no age limit involved in the concept of a fossil. The shells buried in the sands of a modern beach and the bones of a sheep buried in the sands of a recent river flood are just as truly fossils as are the most obscure traces of organisms found in the oldest known deposits. Burial is the only necessary process to produce a fossil, and this is primarily so because it is the fundamental condition of preservation. Dead animals and plants exposed to the atmosphere will soon decay, and their bones and other hard parts crumble to powder. But burial tends to protect these structures, especially if the covering material is dense and impervious to air and water. Even then, the soft tissues of animals and commonly those of plants as well, will undergo a change, the former, unless impregnated with mineral matter, rapidly disappearing, leaving only the bones, shells, or other hard structures. Hence most fossils consist only of the hard parts of the animals, but as we have noted, under favorable conditions, such as the embedding in frozen mud and ice, or the burial in antiseptic peat beds, even the flesh may be preserved for an indefinite period. Still another example of complete preservation of organisms is found in the case of insects embedded in the resinous gum of coniferous trees which, on hardening, has become amber. Some of the best insect-bearing amber is found on the coast of the Baltic Sea, having been washed from submerged beds of older Tertiary (Oligocene) age.

Types of Fossils

We may recognize four types or grades of fossils, based on the manner in which the organisms recorded their presence. These are as follows:

1. Actual remains or the impressions left in the rock after their destruction.

2. Trails and tracks made by animals in transit and marks made by plants dragged over the surface or floating in shallow water. Burrows made by worms and other animals in sand and mud, or in rock also belong here.

3. Structures built by animals from foreign material, such as the shells of certain Foraminifera, formed from cemented sand-grains, and similar tubes constructed by sand-worms.

4. Coprolites of fish, reptiles, and other vertebrates, worm castings and the like.

Of these types the first two are the most important, while the third and fourth groups are of minor significance, except perhaps in the most recent formations. We may briefly review the several types.

Actual Remains

Soft Tissues. — As already noted the soft tissues of animals are preserved only under exceptional conditions, such as becoming embedded in frozen mud and ice, in the resinous gum of trees, etc. Occasionally, also, the soft tissues may become impregnated with, and finally replaced by, mineral matter before they decay. This has happened in the case of some Devonian fish, of which the muscle fibers have been so perfectly preserved that they are readily recognizable under the microscope. Similar preservation of muscle fibers of some Mesozoic reptiles is known. Bodies of animals and, more rarely, of human beings, have become impregnated with mineral matter from the ground in which they were buried, and decay being thus halted, the flesh has been preserved more or less completely. Such was the case with the body of a negro woman, preserved after burial for 57 years, and still more markedly in the case of the body of a Peruvian miner, on exhibition in The American Museum of Natural History, which was impregnated with blue vitriol and other salts after death was caused by the collapse of a mine, probably several hundred years ago.

Impressions of the soft parts are more frequently preserved than the actual tissues. Thus the impressions of the soft-bodied jellyfish have sometimes been perfectly preserved, though the material of the body has decayed. Some of the finest examples of such preservation have been obtained from the very ancient Cambrian shales of British Columbia, and in these fossils, the internal anatomy can frequently be determined (see Fig. 1039). Where the structures are more resistant, as in the case of the membranous wings of insects, the skin of reptiles, and the like, these have left very decided impressions when buried in fine-grained muds, such impressions being often emphasized by a thin film of carbonaceous matter, which is the organic tissue itself reduced to carbon. Classical examples of such preservation of somewhat more resistant tissues are found in the famous lithographic stone of Bavaria, and in the Liassic shales of Württemberg and southern England. In some cases the skin of animals (reptiles) has been preserved in these Liassic muds. A similar preservation of the skin of a dinosaur (*Trachodon*) has been found in the Cretaceous of western North America (Wyoming). (See Chapter XLIV.)

The bodies of some of the lower forms of animal life are protected or upheld by a more resistant organic substance than the fleshy tissues. This is illustrated by the material composing our common bath sponges, and is equally marked, though less familiar, in the case of the lowly marine organisms known as hydroids, where it constitutes a protecting covering for the softer tissue. When buried in sand, this substance, to which the name *chitin* is generally applied, changes to a carbonaceous film, which is the usual state of preservation in which such organic remains are found. The group of the *graptolites*, so characteristic of the older Palæozoic formations, is a typical example of preservation of such material in this condition. (See Figs. 839–842.)

Plant tissues resist decay better than animal tissues and are more frequently preserved. Buried leaves generally change to a film of carbonaceous material in which the veining is still readily recognizable; or they may leave merely an impression, more or less iron stained, upon the surface of the bedding planes, or supplemented by a thin film of mineral matter precipitated by the decaying organic substance.

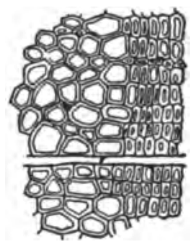

FIG. 753. — A thin section of a silicified wood (*Pityoxylon pealii*) from Gallatin county, Montana, showing the well-preserved cells. The large cells are those of the summer wood, the compressed cells, those of the fall wood. A longitudinal section of a resin tube is also shown. (See Chapter XLV for silicified tree-trunks in the position of growth.) (After Diller, U. S. G. S.)

Woody tissues of buried plants are commonly impregnated with silica or other mineral matter carried by the groundwater in solution. This mineral at first fills all the pore spaces. Later, as the wood decays, it is replaced, molecule by molecule, with mineral matter. Thus perfectly petrified wood is produced in which the entire substance is agate or some other form of quartz, or opal, while the structure of the wood is still perfectly preserved. (Fig. 753.)

Hard Structures. — Many of the lower forms of animal life secrete shells of carbonate of lime (mollusks, brachiopods, Foraminifera, some crustaceans) while others build more solid structures of this material (corals, bryozoans, etc.). Some low plants (nullipores) also precipitate carbonate of lime in and upon their tissues and so produce resistant stony forms. A certain group of organisms (echinoderms) builds an armor of calcareous plates within the outer part of the body, while still another secretes a hard, skinlike covering of lime and horny matter, which is shed each year to be replaced by a new and larger one (crustaceans). The higher animals (vertebrates) all build a resistant skeleton of bone and cartilage within their bodies, besides developing other hard structures such as teeth, dermal plates, spines or scales, and the like. In these internal structures, and sometimes in the external ones as well, the material is in part phosphate and in part carbonate of lime.

All such mineral structures are readily preserved when buried, though solution by percolating waters may remove them in time. On the other hand, such waters often bring additional mineral substance which fills all the pores and cavities left by decaying organic matter. In shells and some other structures, this organic material forms a meshwork upon which the lime was originally deposited. When the pores are filled by deposits of carbonate of lime or carbonate and phosphate of lime, a solid structure of that mineral matter is produced, and the shell or bone may be said to be truly petrified.

Silicification. — If, however, the material filling the pores is silica, then a new process, that of *silicification*, is inaugurated. Silica, being much less soluble than carbonate of lime, will replace that substance, because of the attraction offered by the silica already deposited in the pores. Often this progressive replacement will be manifested by the development of a series of small rings of silica around a central nucleus or starting point. A shell or other calcareous object in the process of being replaced by silica will often be covered with many series of concentric rings. These have been named *beekite* rings after their original discoverer, Dr. Beek. All stages of replacement may sometimes be found in shells or other calcareous structures.

Effects of Silicification. — When the original carbonate or phosphate of lime is replaced by silica, it generally happens that the details of original structure, such as different layers of lime, tubes, canals, etc., are destroyed, although the form may be perfectly preserved. It is a matter of common experience that the fossils in a limestone may thus be silicified while the inclosing matrix is not altered at all. As a result, when such a limestone with silicified shells, corals, etc., is exposed to the atmosphere, or to the solvent action of water, the matrix will be removed, while the fossils will be unaffected. These will then accumulate as a layer of weathered-out fossils upon the surface of the decaying limestone, while in cliffs and ledges of such limestone they will stand out in relief. Many of the best collections of silicified fossils have been obtained from such weathered limestone surfaces. The relative slowness of the weathering process explains why a region which, when first discovered, yielded a great abundance of beautifully preserved, weathered-out fossils, becomes relatively barren after repeated visits of collectors have been made to it, although the unweathered rock may still contain thousands of beautiful specimens in the same state of silicification. Some of these may be obtained by careful etching with dilute acid, which removes the limestone, but this also attacks the still unsilicified portions of the fossil itself.

Excessive Silicification. — Not infrequently the deposition of silica is localized in the fossil, — as, for example, along cracks in the shell or between the plates of an echinoderm structure. In that case, the fossil may become greatly distorted, large ridges of silica forming in the cracks and pushing the fragments apart while still holding them, or in the case of the echinoderm structure, pushing the plates farther and farther apart as deposition of silica goes on, and so greatly enlarging the entire fossil. In this manner, hollow structures are sometimes developed, the interiors of which are lined with quartz crystals, forming *geodes*.

Replacement by Other Minerals. — Many other minerals replace originally calcareous shells, the most common among these being iron pyrites. Pyritized fossils are often among the most striking of natural objects.

Original Silicious Structures. — Some organisms secrete hard structures of silica instead of lime, as for example, the Radiolaria, a group of lowly marine organisms swarming in the pelagic districts of some parts of the oceans (Fig. 827). Diatoms, a group of simple plants, likewise secrete silicious structures (*frustules* Fig. 795 *c*), while many sponges develop a series of separate or interlocking silicious rods or spicules which interpenetrate the other tissues and which may project as glass fibers at the base of the sponge. (See Figs. 829, 831 *a*, *b*, 832.) Such structures are generally preserved without change, though it also happens that in the course of time they may be replaced by carbonate of lime. Thus sponges, originally with a skeleton framework of silica, but now entirely calcareous, are not unknown in some formations.

Special Cases of Preservation of Vertebrates. — Complete skeletons of vertebrates, including those of man, are sometimes found in abundance because of peculiar conditions of preservation. Many famous occurrences of perfect skeletons have been recorded from caverns both in Europe and America, and from such cavern deposits, the most complete record of the history of early man has been obtained. A unique example of the preservation of vertebrates is found in the case of a former asphalt pool near Los Angeles, California, which became the burial place of an extensive fauna. This will be more fully described in the next chapter.

FIG. 754.— Internal mold of *Arca* (*c*), enclosed in rocky matrix; *a*, cavity occupied by the shell. (After d'Orbigny.)

Molds and Casts. — In the mud or sand in which the shells or other hard structures are embedded, an impression or mold of the exterior of this object will be preserved, and the perfection of detail of the impression will be proportionate to the fineness and compactness of the inclosing material. When the original structure is hollow, as in the case of shells or echinoderm tests, the filling of mud forms an internal mold which exactly reproduces the form of the animal body which occupied that shell or test (Figs. 754, 756, and 757). When percolating waters remove the original shell, the molds alone remain, and molds of the exteriors of shells are not uncommon in the more porous rocks (Fig. 755).

FIG. 755. — Exterior and interior mold of a pelecypod shell. (After d'Orbigny.)

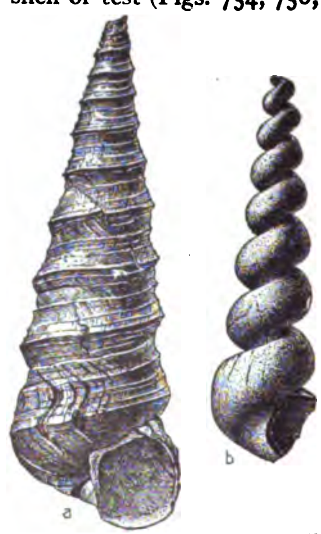

FIG. 756. — A gastropod shell (*Turritella mortoni*) and its internal mold (Eocene).

Since these reproduce the external character of the shell in reverse, a cast may be taken from such a mold with modeling clay, dentist's wax, plaster of Paris, or other substance, and such a cast will reproduce, with more or less fidelity, the surface characters of the original shell. Sometimes casts are formed in nature by the subsequent infiltration of mineral matter into the cavity left by the solution of the shell or other original structure. Such natural casts of coral impressions in limestone have been made by deposits of silica. The Tampa region of Florida is noted for such casts or coral "pseudomorphs." When the original shell is thin, the external and internal molds, after removal of the shell, may come into close juxtaposition by the pressure of the overlying rock mass, and the characters of the exterior become impressed upon the surface of the internal mold. Many pelecypod shells are thus represented in the older rocks.

FIG. 757. — A fossil gastropod (*Sphærodoma ponderosum*), Carbonic, showing filling with hardened sand where shell is broken away.

Tracks, Trails, and Burrows

Foot-prints. — The foot-prints left by animals upon a muddy surface may readily retain their shape as the mud dries, and remain intact until the mud is softened again by renewal of rainfall. In regions of limited rainfall, such foot-prints may remain without change for many years, a case being recorded from the Sahara Desert where the foot-prints of a caravan were still recognizable fifteen years later. If wind-drifted sand, or the sand and mud washed over the surface by a sudden flood, buries these foot-prints, they are likely to be permanently preserved. The covering of sand on solidification will preserve a relief mold of the foot-print (Fig. 758) and sandstone layers with such foot-prints in relief are more often preserved than actual impressions because the latter, if made in clayey mud, are likely to be destroyed in quarrying operations which again uncover them. With care, however, such actual impressions may be obtained, and there is, of course, one for every relief mold.

Foot-prints of this type are common in the Triassic sandstone of the Connecticut Valley and of New Jersey, and they also occur in the Triassic sandstones of Europe. In general, such foot-prints indicate that the accumulation of the material in which they were made took place upon the land, along river flood-plains, playas, or other similar areas. Furthermore, such foot-prints are more common in deposits formed under semi-arid or arid conditions than in those formed in pluvial climates because, in the latter, the mud seldom remains hard enough for a sufficiently long time to preserve the impressions until they are buried.

FIG. 758. — Slab of red sandstone (Triassic) showing the relief impressions of mud-cracks and of saurian foot-prints on the under side of the slab. This represents the solidified sand which covered the original mud-cracked layer of clay in which the foot-prints were made. Newark formation, New Jersey.

Many foot-prints may, of course, be made by a single animal, while no part of the actual animal remains, nor need the region in which the foot-prints were made have been the normal home of the animal. Indeed, the peculiar occurrence of many such impressions points to a temporary visit of the animals that made them, possibly from a distant home. If the animals perish in the region where their foot-prints are made, their skeletons may not remain long enough

FIG. 759. — *Arthrophycus harlani.* Natural relief molds of trail on under side of a slab of Medina sandstone (about one third natural size). (Courtesy N. Y. State Museum, John M. Clarke, Director.)

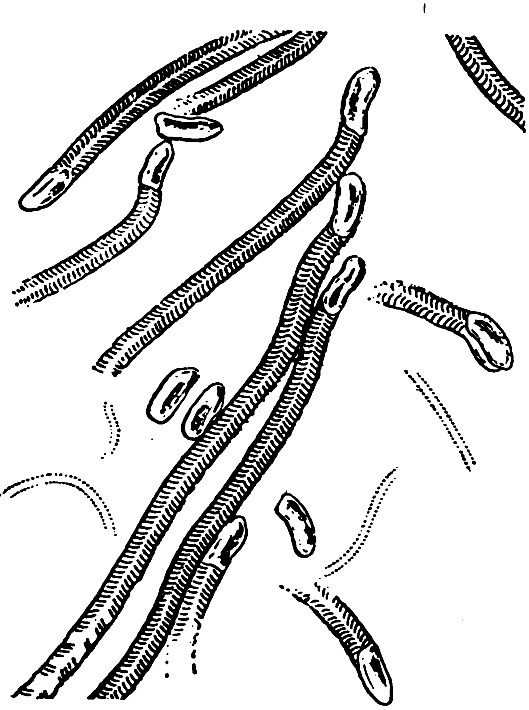

FIG. 760. — *Climatichnites wilsoni* (Logan). A track, $\frac{1}{25}$ natural size, and terminal impression. Potsdam sandstone, Mooers, Clinton county, N. Y. (After Walcott.)

intact to permit their burial by the drifting sands or other agents. Thus many formations like the Triassic sandstone, abounding in foot-prints, are poor in skeletal remains.

Trails. — Animals crawling upon or just beneath the surface of the sand and mud commonly leave a definite trail, which may be preserved in the same manner as the foot-prints. As in their case the relief mold on the under side of the covering stratum will be more commonly preserved than the actual trail; at any rate it is

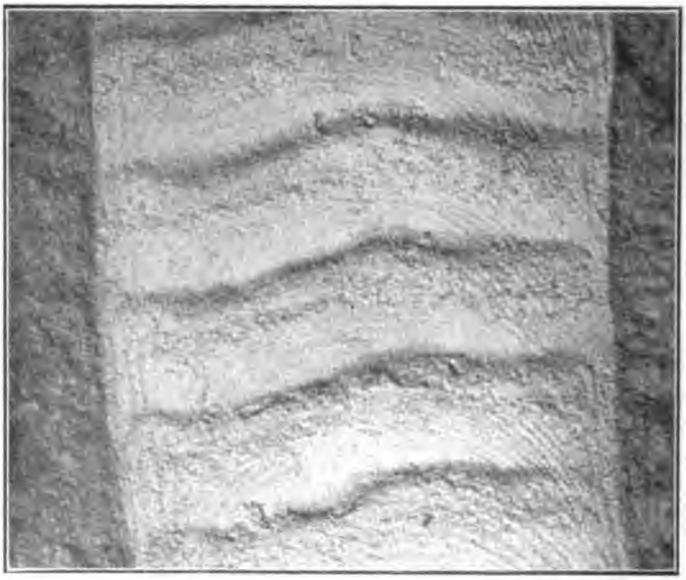

FIG. 761. — *Climatichnites youngi* (Chamberlin). Portion of a regular trail showing forward-curving transverse furrows made by pressing the beach sand backwards in creeping, also curved lines made by the impression of the very fine forward-arching transverse ridges on the ventral surface of the animal. Potsdam sandstone. (Somewhat reduced.) (After Walcott.)

more frequently represented in collections (examples: *Arthrophycus*, Fig. 759; *Climatichnites*, Figs. 760, 761). On fine-grained rocks, especially such as are formed on playas or river flood-plain surfaces, the delicate trails of worms and of insects are not infrequently found.

Floating jellyfish in shallow water may drag their tentacles upon the bottom mud, and floating seaweeds may form similar groovings if they drag upon the bottom. Owing to the fact, however, that waves and currents quickly obliterate such groovings, they are seldom preserved long enough to be permanently buried.

FIG. 762. — *Scolithus linearis* Haldemann. Lower Cambrian (Antietam) sandstone. Pebble near Washington, D. C. (After Bassler.)

Burrows. — Burrows made by worms in sand, and by mollusks, echinoderms, and other animals in rock, serve as a temporary, if not permanent, home for these organisms, and in a measure approach the class of artificial structures. Burrows in loose material are preserved when the abandoned cavity is filled with sand or mud. Such pencil-like rods of sand are often found in certain sandstones, penetrating them in a vertical direction. A rock of this type, found in northern Scotland, is called on this account a *pipe-stone*, and similar tubes, called

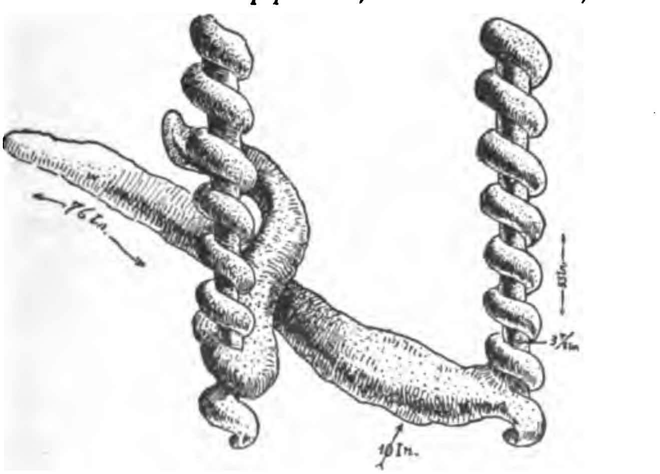

FIG. 763. — Two views of a specimen of the Devil's Corkscrew (*Dæmonelix*), showing the spiral and basal portion of the rock-filling. The central axis is not a part of the original, but is left for support of the spiral. (After Barbour.)

FIG. 764. — Mound or nest of termites or white ants in laterite region of Africa. (After Branner, from *Principles of Stratigraphy.*)

Scolithus, are found in early Palæozoic sandstones (Potsdam, etc.) of North America (Fig. 762). (See also Fig. 791, p. 67.)

What appears to be a remarkable large corkscrew-like burrow, ending below in a large tubular cavity, is found in continental sandstones of Tertiary age in western North America (Nebraska, etc.) and is known as the Devil's Corkscrew or *Dæmonelix* (Fig. 763). If this is a burrow, it appears to have been made by rodents, the skeletons of which are not infrequently found in the basal portion. From certain structural characters of the core, however, it has also been supposed that it represents a plant which grew in this manner and was subsequently buried.

Artificial Structures

Dredging in moderate ocean depths often brings to the surface delicate tubes constructed of grains of sand bound together by

FIG. 765. — White ants' (termites') nests of earth. Matto Grosso, plains of Upper Paraguay. (After Branner, from *Principles of Stratigraphy.*)

organically secreted substances. These tubes are constructed by marine worms, which use them as a protective covering or dwelling place. Such structures, built of foreign material, are also produced by some other animals, but as a rule they are not common except in the more highly organized types. The cells constructed by the honey-bee, and the "nests" built by wasps and those of ants and termites (Figs. 764–766), may be regarded as the highest type of

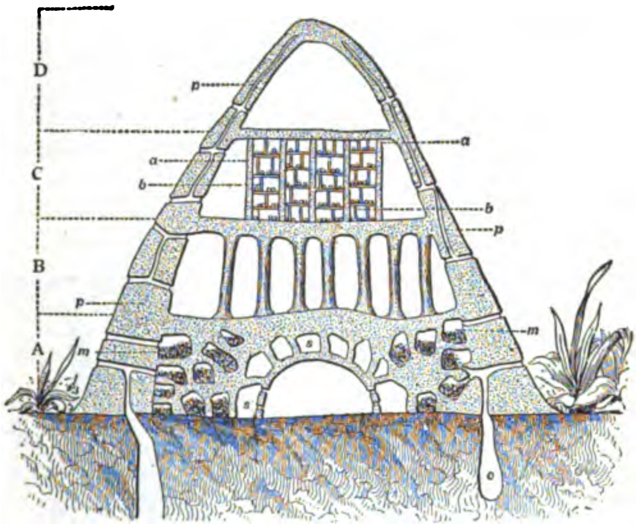

FIG. 766. — Diagrammatic section of termites' nest. (After Houssay, from Thompson.) *A*, Ground apartment; *B*, nest in hall supported by pillars; *C*, place where young termites are hatched on shelves, *a–b*; *D*, well aired empty attic; *a–b*, shelves for hatching; *c*, holes in ground from which material for nest was dug; *m*, storage chambers; *p*, passages in wall; *r*, royal chamber (large vaulted room on ground floor) in which king and queen are imprisoned; *s*, chambers of workers. The whole structure is sometimes 10 to 15 feet in height.

artificial structures among invertebrate animals, but these are seldom formed under conditions that make their preservation in the rock-forming material possible. More important in this connection are the structures made by man, his flint and other implements, pottery, and buildings, and these are often preserved in the younger deposits of the earth's crust. In some cases entire cities may be buried and become fossils, as was the case with Herculaneum and Pompeii, buried by the ashes and lavas of Vesuvius in A.D. 79 (Fig. 72, p. 127, Pt. I). Excepting those made by man, artificial structures are of little importance as fossils.

Coprolites, etc.

The excrements of some vertebrates, such as fish (Fig. 767), and some of the Mesozoic reptiles, have a characteristic appearance which permits of their identification. They are chiefly of importance as indications of the presence of such animals in the waters in which the rocks inclosing them were deposited. The excrements of sea fowl, though not of distinctive form, are of peculiar chemical character, and often form, as we have seen (p. 322, Pt. I), extensive deposits of mineral fertilizer or guano. The stomach-stones or *gastroliths* found in the body cavities of fossil reptiles, and which are supposed to have assisted in the mastication of food, have peculiar surface characters, by which they can be recognized, even when found unassociated with the skeletons.

FIG. 767. — Coprolite of a fish. (After d'Orbigny).

On flat, sandy shores, at low tide, we may often see heaps of sand which have the appearance of consolidated masses of heavy twine. These are the castings left by marine worms, and are formed of the sand which they have passed through their bodies in order to extract from it the organic nutriment mingled with it (Fig. 768). Some formations appear as though all the material composing them had been passed through the bodies of worms, and the term vermicular rock is applied to them. A great, early Palæozoic limestone in northern Scotland has been interpreted as formed of such worm castings of calcareous mud.

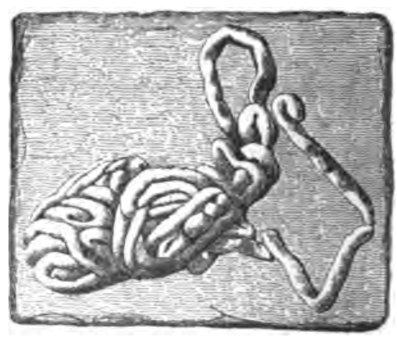

FIG. 768. — Fossil worm casting (*Lumbricaria colon* Münst.). Lithographic beds, Solnhofen. Natural size. (From Zittel.)

DEFORMATION OF FOSSILS

By pressure of superincumbent rocks, or by the compressive force responsible for the deformation of rocks, the included fossils may be deformed in various ways. Some of these are illustrated in the adjoining figures (Figs. 769 *a–d*).

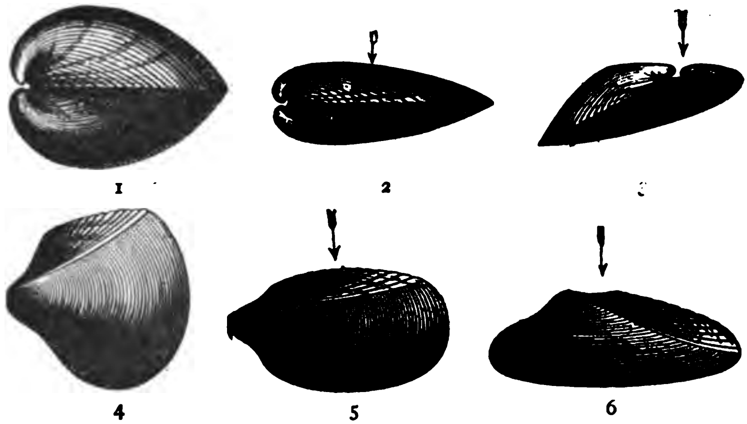

FIG. 769*a*. — Deformation of pelecypod shell (*Protocardium hillanum*, Cenomanian) by pressure. (After d'Orbigny.) 1, anterior view of perfect shell; 2, 3, deformation by pressure; 4, left valve, perfect shell; 5, 6, deformation by pressure.

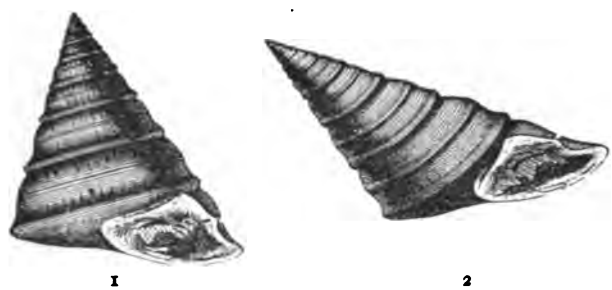

FIG. 769*b*. — Deformation of gastropod shell (*Pleurotomaria fleuriausa*) by pressure. 1, perfect shell; 2, depressed. (After d'Orbigny.)

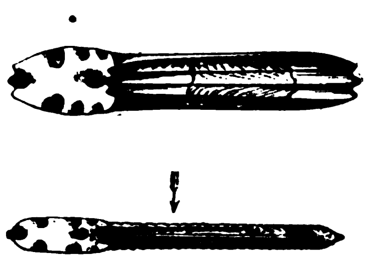

FIG. 769*c*. —Deformation of ammonite shell (*Hildoceras bifrons*) by pressure. Upper perfect shell, lower compressed. (After d'Orbigny.)

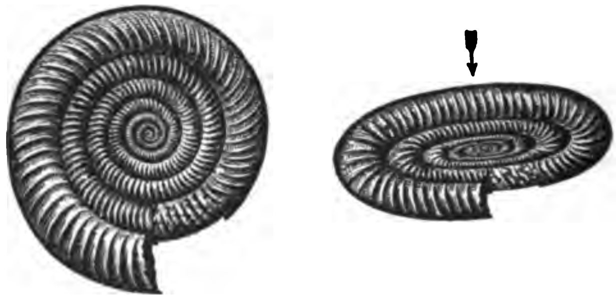

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FIG. 769*d*. — Deformation of ammonite shell (*Calloceras nodotianus*) by pressure. 1, perfect; 2, depressed shell. (After D'Orbigny.)

INDEX FOSSILS AND FACIES FOSSILS

It is a familiar fact that certain animals living in the sea are restricted to certain kinds of environment, the chief element of which is the nature of the bottom. Thus the common clam, *Mya arenaria*, lives buried only in muds rich in organic remains and forming parts of tidal flats. Some other mollusks and many brachiopods live only where the bottom is formed of rapidly hardening material (lime, etc.) to which they can attach themselves. Again, others like the hen clam (*Mactra*) of the Atlantic coast will live only upon a sandy bottom. As the sea bottom at any one time presents a great variety of characters or *facies*, as it is called, it is evident that each will have its peculiar type of organisms in addition to others of less restricted habitat, and that as fossils, they will always be associated with a definite rock type. Such fossils are called *facies fossils*, and they will be found only in sediments of similar character and will be absent from others.

When fossils are restricted to a limited vertical range, representing organisms which lived for a relatively short period of time only, giving way thereafter to other types, they become satisfactory indices of that particular time period in the earth's history, and they will serve to identify a particular level or horizon in the geological series. Such fossils are called *index fossils*, and they are of the greatest importance to the stratigraphic geologist, for by their aid he identifies his formations in different localities. It is evident that the best index fossils are those which have the greatest horizontal or geographic, with the smallest vertical or time, range, and organisms which can be distributed by flotation serve this purpose to the best advantage. Modern examples are the *Argonauta* (Fig. 896) and the related *Spirula* (Fig. 770), the shell of which is found cast upon the shores as far north as Long Island, N. Y., though the animal lives only in deep tropical waters. Among the best of such widespread index fossils of limited vertical range in the older Palæozoic series are the graptolites (Fig. 840, p. 99), and in the Mesozoic the ammonites (Fig. 905, p. 134). While these two groups often have a worldwide distribution, the majority of index fossils are limited to small areas. Thus the fossils of Europe are, on the whole, distinct from those of the same horizon in North America, and those of eastern North America often differ markedly from those of the western region. This is generally due to the fact that these organisms were derived from distinct oceanic provinces, these older oceans differing in their organisms as the several oceans do to-day. They may also represent local development in circumscribed epeiric seas.

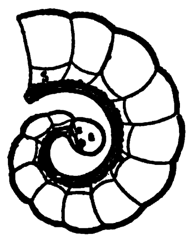


FIG. 770. — *Spirula peronii.* Part of shell of a modern deep-sea cephalopod, frequently found floating in the pelagic district far from the home of the animal. *s*, siphuncle; *a*, protoconch; *p*, prosiphuncle. Enlarged. (See Fig. 897, p. 130.) (From Steinmann.)

Fossil Faunas and Floras

The totality of the animals of any one locality at a given time constitutes its *fauna* for that period. The similar assemblage of plants constitutes its *flora*. Faunas and floras vary from place to place with the variations of the physical conditions at any period of time. But faunas and floras may overlap, some members of one fauna or flora extending into the territory of an adjoining one. This makes possible the correlation of distinct faunas or floras which, nevertheless, belong to the same geological horizon. In the absence of distinctive index fossils, reliance upon the faunas or floras as a whole becomes necessary. Thus two distinct faunas, the Ithaca and the Naples, each characteristic of a part of the Upper Devonian rocks of North America, are recognized as contemporaneous faunas, because in intermediate sections they occupy the formations in a repeatedly alternating manner as shown in the following diagram (Fig. 771).

Finally, it should be noted that there are cosmopolitan and provincial faunas and floras, the former being widespread over the earth, the latter restricted to certain provinces. Marine

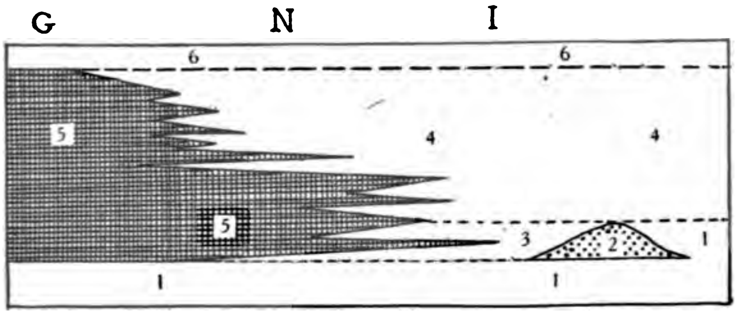


Fig. 771. — East West section (restored) across central New York to show the contemporaneous characters of two faunas in the Upper Devonian. The section must be read with the understanding that beds at the same elevation above the bottom line were deposited at the same time. *G*. Genesee Valley. *N*. Naples region. *I*. Ithaca region. (1) Beds occupied by the Hamilton fauna. On the east (right), this fauna continues longer (through 250 feet of strata), and is separated from the Ithaca region by a sand bar 10 miles in width (2); west of this bar, the Hamilton fauna, being isolated, becomes modified into the lower Ithaca fauna (3). At the same time the sea was invaded from the west (left) by a foreign fauna, the Naples fauna (5), the two existing side by side and shifting position from time to time. As the bar (2) became submerged, the Hamilton fauna and Ithaca faunas commingled, producing the upper Ithaca fauna (4) which extends through 1200 feet of strata, while the Naples fauna (5) continued through the same strata farther west, the two faunas frequently shifting their positions. Note that at Ithaca only the indigenous Ithaca fauna was enclosed in the succession of sediments; in the Genesee region only the Naples fauna; in the Naples region, the Naples fauna occurs in the lower half of the series and the Ithaca fauna in the upper half. Finally the Ithaca fauna became further modified by evolution, and by the arrival of new immigrants, to form the Chemung fauna (6). (Modified after J. M. Clarke.)

provincial faunas generally represent new developments in regions which for the time being are isolated or cut off from intercommunication with the open ocean. Land floras and faunas may be similarly restricted by barriers of topographic or climatic origin, or by the distribution of food supply or of their natural enemies. Provincial faunas and floras of one geological epoch may expand and become cosmopolitan in the next succeeding epoch.

Fossils as Indications of Continental or Marine Sedimentation

Plants. — All plants other than seaweeds (marine algæ) are land-derived, though some, like the mangrove and the eel-grass, grow in shallow sea-water. When only remains of land plants, such as ferns and higher types, are present in the rocks, it is generally safe to assume that these rocks were deposited upon the land, as lake or playa sediments, or as river flood-plain, alluvial fan, or delta deposits. They may, however, also represent the deposits in estuaries where the abundant fresh water kept out the marine fauna. Finally, it must be noted that land plants are often rafted far away by marine currents and that abundant remains of land plants have been dredged from abyssal depths of modern oceans at a considerable distance from land. Such deposits are, however, generally, if not always, associated with the remains of marine organisms.

Animals. — Many classes of animals, such as the corals, brachiopods, etc., are wholly marine, and their presence in rocks indicates almost certainly a marine origin unless they represent the fossils of older marine rocks re-worked by agents of continental sedimentation. Other classes have both marine and non-marine representatives. Mollusks are found in both salt and fresh water, but the fresh-water forms have certain characteristics which make it relatively easy to recognize them (Figs. 772–773). One division of the Mollusca, the snails or gastropods, also has representatives upon the dry land, the common garden and woodland snail (*Helix*, Fig. 774) being the most typical example. In the Hawaiian Islands and other districts, snails live even upon trees and shrubs, but all of these have characteristics which the trained student may readily recognize. Still other animals live sometimes in the sea and sometimes in rivers

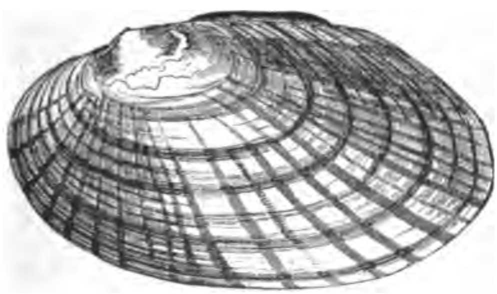


Fig. 772. — A fresh-water mussel (*Unio radiatus*). Natural size. (From Binney and Gould.)

which enter it, as is the case with the salmon, which returns to the rivers to deposit its eggs and is, incidentally, captured as a result of this return. The young spend a part of their life in the rivers

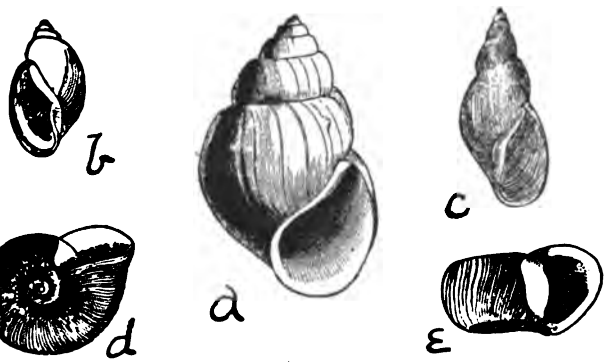


FIG. 773. — Fresh-water gastropod shells. *a*, *Paludina*; *b*, *Physa*; *c*, *Limnæa*; *d*, *Planobis* (bottom view); *e*, side view of the same. (After Binney and Gould.)

before they enter the sea. In the case of fish, it appears that during the early periods of geological time they were wholly restricted to rivers, entering the sea only in the later periods of the earth's history. This seems also to be true of some other organisms, such as the horseshoe-crab.

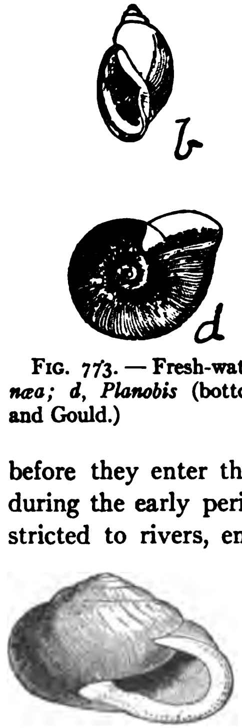


FIG. 774. — The common snail living on the land, in moist woods and gardens (*Helix albolabris*). Natural size. (From Binney and Gould.)

FOSSILS AS INDICATORS OF CLIMATE

Plants are the best indices of climate upon the land, and when the remains of palms and other plants, which now grow only in tropical regions, are found in rocks deposited in regions now characterized by temperate if not Arctic climates, we infer that at the time of the formation of these rocks the climate of the region was much warmer than to-day. The occurrence of cycads in Mesozoic rocks in the northern United States, Canada, and even Alaska and Greenland, indicates that at one time the climate of these regions was not unlike that of Cuba to-day.

Some marine animals, like the reef-building coral polyps, can live only in waters free from ice, which would destroy these soft animals, living as they do so near to the surface of the sea. The finding of coral reefs in the Silurian deposits of New Siberia within the present Arctic circle, therefore, suggests forcibly that the waters of that region were free from ice the year round in Silurian time, and hence that the climate of the region was at least subtropical.

Fossils — The Historical Record of Organic Evolution

Although the geologist uses fossils primarily as indices, to determine the geological horizon, and the physical conditions of origin, of his sediments, he cannot wholly neglect the biological aspect which fossils have, namely, their unique value as the actual historical record of the evolution of plant and animal life on earth. Fossils must indeed be regarded as representing the successive steps in the progress of organic development, and though only certain parts of the animals and plants of the past are preserved, so that the record is an incomplete one, still it is sufficiently comprehensive to enable the student not only to recognize the verity of organic evolution, but also to determine many of the most fundamental principles and laws which have governed such development.

That the modern animal and plant world has developed by natural methods from preëxisting simpler forms has been held by many philosophers even in antiquity, and has been clearly demonstrated by the labors of biologists in many fields. It was, however, not until the fossils of the various geological formations were studied, and their chronological succession determined, that the actual historical record of such development became available. True, the older students of fossils attempted to explain this record as one of successive special creations, rather than of natural development. Such was the attitude taken by the great French naturalist, Cuvier (portrait, Fig. 6, p. 24, Pt. I), the father of comparative anatomy, and the student of the vertebrate remains found in the Tertiary rocks of the Paris Basin. His contemporary, Lamarck, however (portrait, Fig. 7, p. 24, Pt. 1), the student of the invertebrate fossils, especially the Mollusca of that region, was an avowed evolutionist, believing in the natural descent of the modern from the ancient species which he found as fossils in the strata. Lamarck also formulated a theory of the causes of modification of the organisms, these causes being, first, the influence of the environment upon the organism in forcing it to change its characters in an adaptive way from generation to generation, and second, the influence of use or disuse, in causing, either the further development and the perpetuation of an organ, or a part of the animal's body, which had newly appeared, or causing the atrophy and final disappearance of old organs or parts, which were no longer of use to the animal. Lamarck held that characters newly acquired by animals and plants during their lifetime were subject to inheritance by their offspring, and were thus perpetuated. These several doctrines are generally grouped together under the name of the "Lamarckian factors of Evolution," but their validity is questioned by many naturalists, especially those who interpret them in the narrow sense in which they were originally applied by Lamarck himself.

FIG. 775. — LOUIS AGASSIZ. (By permission of Houghton Mifflin Co.)

It was, however, Louis Agassiz (1807–1873, portrait, Fig. 775), a pupil of Cuvier, who first showed the true relationship which fossil animals held to those of the modern world, although, strangely enough, Agassiz never accepted the doctrine of evolution, but, like his teacher, regarded the animals and plants of the successive geological periods as older, simpler creations, as discarded trials, so to speak, of the Creator, in the fashioning of

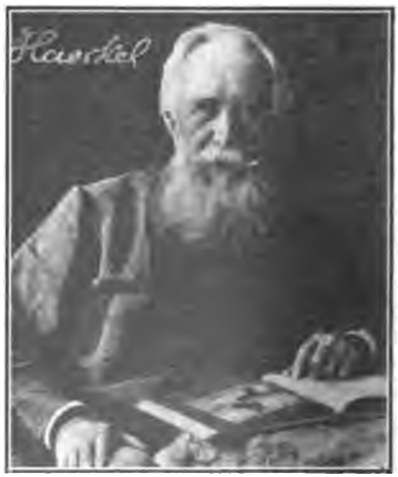


FIG. 776. — ERNST HAECKEL.

the more perfect modern forms. But to Agassiz belongs the credit of pointing out that the young of the modern forms resembled, in their essential characters, the adults of similar forms in the immediately preceding geological period, more than they did their own adult stages. A contemporary of his, the biologist and geologist, Carl Vogt, however, interpreted this similarity as indicating genetic relationship. The brilliant naturalist, Ernst Haeckel (1834–1919, portrait, Fig. 776), embodied this phenomenon in his "Law of Biogenesis," according to which the young of higher, or more recent, forms, repeat the adult characters of their ancestors which lived in former geological time, and this doctrine of the recapitulation of ancestral characters has become the cornerstone of philosophic palæontology. The German biologist, Karl Ernst von Baer, known as the father of the science of embryology, had formulated a similar law, though he compared the embryonic stages of modern forms with the adult stages of existing simpler types, finding a similarity which at best is only a superficial one.

FIG. 777. — ALPHEUS HYATT.

The first demonstrations of the correctness of the recapitulation theory, in the sense in which it is accepted by palæontologists (not the von Baer sense), were made by American palæontologists: Alpheus Hyatt (1838–1902, portrait, Fig. 777), for invertebrate animals, and Edward D. Cope (1840–1897), for the vertebrates. Hyatt was able to show that the successive stages in the shell of an ammonite, found by breaking away the later or maturer shell-stages, corresponded exactly in character to those of the adults which preceded them in time, and which represented their ancestors.

A few illustrations will make this clear. In the Cretaceous beds of Texas and Mexico occurs an ammonite (*Placenticeras planum*, Fig. 778), the adult shell of which has a compressed outer (ventral) portion, flattened and bordered on either side by elongated nodules. In somewhat younger beds of the same region occurs another form (*Stantonoceras guadaloupe*, Fig. 779), the adult of which has a broad outer or ventral surface, bordered by prominent nodules, while a second series of elongated rib-like nodules is found on each side of the shell. But when this species is only half grown (as can easily be shown by breaking the outer whorls of the shell) it has precisely the form and ornamentation of the adult shell of the previously mentioned species (*P. planum*) which precedes it in time. This is shown in outline in the cross section of the inner whorls of this species in Fig. 780 *b*. In the same or somewhat younger beds is found a third species (*Stantonoceras pseudocostatum*), which is still more advanced, having a very broad, gently arched ventral or outer surface, and flat sides, marked by coarse irregular cross-ridges or ribs. The half-grown individual of this species resembles in all respects the adult of the preceding species (*S. guadaloupe*) while the young resembles the half grown *S. guadaloupe* or the adult *Placenticeras planum*. This is shown in the cross section, Fig. 780 *a*. Thus the form and surface features of the adult stage of the first species are repeated in the adolescent stage of the second, and in the early youth of the third species, while the adult features of the second species reappear in the adolescent period of the third, the most specialized of the three. Such progressive changes are shown in the other characters of the ammonite shell as well. As will be seen by a reference to Figures 905 and 906, pp. 134–135, the line of junction between the shell and the transverse partition or septum, that is, the so-called suture, is very complicated, being strongly lobed and fluted. Every ammonite, however, when young has a much simpler suture, which recalls that of the adult *Ceratite* (Fig. 904, p. 133), which lived mainly in the Triassic period, that is the period preceding those in which ammonites flourished in abundance (Jurassic, Comanchean, and Cretaceous). At a still younger stage, the suture of the ammonite resembles that of the adult *Goniatite* (Fig. 903, p. 132), which flourished still earlier, being most characteristic of the late Palæozoic. The adolescent ceratite too has a goniatite type of suture, while at a still earlier stage in its development, its suture is without the complication of lobes and saddles, and so resembles that of the adult of the early nautiloids, which alone represented the coiled cephalopods, in early Palæozoic time. The young or adolescent goniatite too is essentially a nautiloid, and often does not assume its distinctive characters until it approaches maturity. Thus it is evident that the late Palæozoic goniatite passed through a nautiloid stage in its own development, while the early Mesozoic ceratite passed first through a nautiloid, and then through a goniatite stage, after which it acquired the adult characters. The later Mesozoic ammonites finally skipped the nautiloid stage, beginning with the goniatite stage.

FIG. 778. — *Placenticeras planum*, adult. End view showing flattened venter margined by nodes, the condition found in the young of *Stantonoceras*. One half natural size.

Then they passed through the ceratite stage, after which they acquired the adult ammonite characters of the suture (Fig. 781). The several types of sutures are illustrated in the figure (Fig. 782) on page 58.

FIG. 779. — *Stantonoceras guadaloupe.* *a–b*, side and end view of the adult; *c*, a broken specimen showing the differently shaped inner whorls; *d*, section of the young stages. (All reduced.)

Another illustration may be given from the Gastropoda. In Eocene times the species of the genus *Fusus* had rounded whorls separated by deep depressions and marked by continuous regular transverse wrinkles or ribs, and by simple

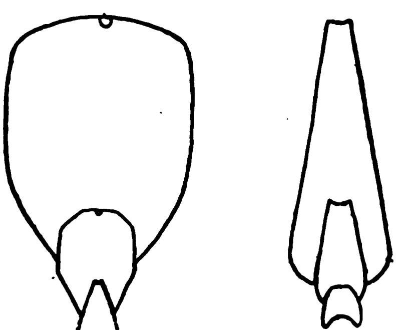


FIG. 780. — *a*, Section of *Stantonoceras pseudocostatum*, showing changes in form of shell (reduced). *b*, Section of young stages of *Stantonoceras guadaloupe* (enlarged) showing change from young, rounded, to later compressed stages. (For adult see Fig. 779.)

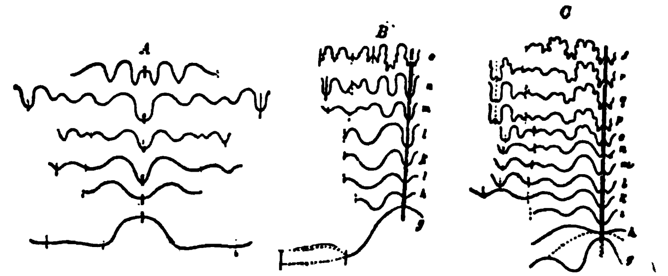


FIG. 781. — Successive stages in the individual development of the sutures in ammonoids. *A*, a goniatite (*G. diadema*); *B*, a ceratite (*Tropites subbullatus*); *C*, an ammonite. (From Zittel.)

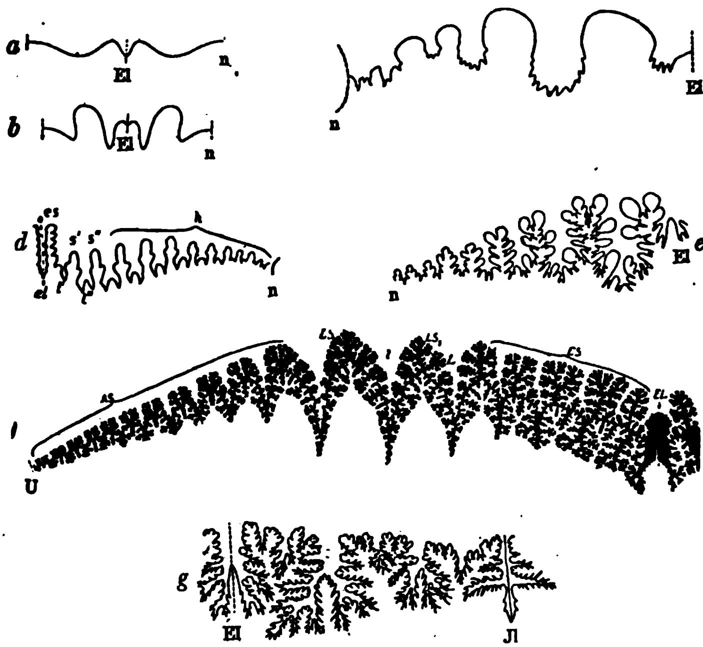


FIG. 782. — Suture lines of ammonoids. *a–b*, goniatitic suture (*a*, *Anarcestes subnautilisius*, Middle Devonian; *b*, *Gephyroceras intumescens*, Upper Devonian: *c*, ceratitic suture (*Ceratites nodosus*, Muschelkalk); *d–g*, ammonitic sutures, showing progressive increase in complexity; *d*, *Medlicottia primas* Permian; *e*, *Phylloceras nilssoni*, upper Liassic; *f*, *Pinacoceras metternichi*, Upper Triassic (space between two sutures blackened); *g*, *Lytoceras liebigi*, Upper Jurassic. *El*, *el*, external lobe; *es*, external saddle; *Ll*, first, *ll''*, second lateral lobe; *Ls* and *s'*, first, *l* and *ll''*, second lateral lobes; *As*, accessory lobes and saddles; *Jl*, internal lobe; *n*, suture line. (After von Stromer and Zittel.)

spiral lines (Fig. 783). In later Tertiary time, the adult whorls became angular, and the ribs became contracted into nodules or "nodes" on the angulation, while additional spiral lines appeared between the original spirals. (See Fig. 888 *e*.) The young of these later, more specialized species, however, are in all respects the counterparts of the adults of the early Tertiary species. In other words, the later Tertiary species repeat, or recapitulate, in their own youth the adult characters of their early Tertiary ancestors.

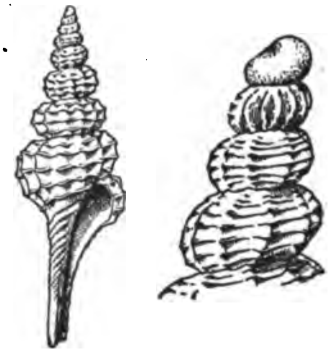


FIG. 783. — *Fusus asper* (Eocene); entire shell, and apical portion enlarged.

Finally, the most characteristic species of *Fusus* in the modern sea also reach the angular and noded condition, but this is acquired in the adolescent instead of the adult stage, and is further complicated by the development of a large number of spiral lines, whereas there are few in the Tertiary species (Fig. 888 *e*). In the adolescent stage these species have the characters found in the later Tertiary species, but in their very young stages they correspond to the adult of the early Tertiary species, having all the simplicity of that shell. There are also in the modern ocean more specialized species, in which the noded condition is restricted to the adolescent stage, while in the adult the nodes have become confluent into a continuous ridge or keel. Other species, still further modified in the adult, are known, and as the new, more specialized characters are added in the adult, the less specialized characters are pushed farther back in the life history; that is, they appear at earlier and earlier stages in the individual development, while some of the earliest stages, those corresponding to the adult characters of the primitive species in early Tertiary time, may be dropped out altogether.

The study of the several stages in the development of the individual (ontogeny) and the comparison of these stages with the life history of the race to which the individual belongs (phylogeny) has not only proved that each individual repeats in its own development the adult characters of its immediate ancestors, but also, that these ancestral characters are passed through at progressively increasing rates. Moreover, it has shown that at any period of time, when the race as a whole has advanced to a certain position, there are generally some species, which lag behind, at least in some characters, so that in certain respects they resemble the adults of more primitive species. These are called *retarded* individuals or species. Others there are which pass beyond the condition reached by the average of the species, and so foreshadow the characters which will be normal for the race at a future time. These are called *accelerated* individuals or species.

In the examples already cited from the genus *Fusus*, which at the present time has most of its species in the noded and many-spiraled stage, we find illustrations of both retardation and acceleration. There are a few existing species which never reach the angular and noded form, although they develop numerous spirals. They therefore retain the form of the whorl which was characteristic of their ancestors. In this respect they are retarded. Other species pass through the noded stage, and develop a median ridge or keel, and still others pass through the keeled stage early in adulthood and lose the keel when fully grown, thus adding a new stage. Both of the characters last mentioned, the keel, and the rounded, but ribless stage, which succeed it in some species, are more advanced than those possessed by the majority of the species of the genus which exist to-day. Therefore the species thus characterized must be considered as accelerated in development. As we have seen, however, they pass through all of the ancestral stages that the average existing species passes through, only at a more rapid rate.

The study of large series of shells of the same and related species has further shown that characters arise progressively, and always in the same order, and, further, that the new characters appear first in a very subdued manner, becoming more and more pronounced as development progresses. In other words, the development is a continuous one, progressing along certain few, and generally determinable, paths, though these paths vary for different groups or "genetic series." Such continuous and progressive development in definite directions is called *orthogenetic development* or briefly *orthogenesis*. Orthogenetic tendencies are seen both in individual development or ontogeny (ortho-ontogenesis or ortho-ontogeny) and in racial development or phylogeny (ortho-phylogenesis or ortho-phylogeny). This principle of orthogenesis, together with

FIG. 784. — CHARLES DARWIN.

that of acceleration and retardation, has become the very corner-stone of modern philosophic palæontology.

FIG. 785. — ALFRED RUSSEL WALLACE.

When it is recognized that the development of organisms proceeds in all directions, though for each series there is a relatively small number of directions along which development takes place, it is apparent that, again and again, the development of certain characters may be carried so far that they will become harmful to the organism possessing them, that, in other words, they will be out of harmony with the requirements of the environment. In other cases, characteristics which adapt the organism perfectly to a certain environment will be no longer serviceable, or may even be harmful, when that environment changes, and the organism finds it impossible to migrate to a new environment. Under such conditions the organism must perish, while others, without such characters, or with those which especially adapt them to the changing environment, will continue to exist and pass these characters on to their offspring. This is the principle of *Natural Selection* first given to the world by Charles Darwin (1809–

FIG. 786. — THOMAS HENRY HUXLEY. (By permission of D. Appleton & Co.)

1882, portrait, Fig. 784) in 1858–1859[1] and simultaneously announced by Alfred Russel Wallace (1822–1913, portrait, Fig. 785). It was rapidly accepted as a working hypothesis by scientific men as well as by laymen, leading to the adoption of the doctrine of evolution itself; and to this acceptance no one has contributed more than Thomas Henry Huxley (1825–1895, portrait, Fig. 786), whose vigorous writings in defense of evolution and of Darwinism rapidly silenced the voices of its opponents. The principle of Natural Selection has come to be of fundamental significance in all biological studies, and its discovery and announcement mark the beginning of a new epoch in the intellectual development of the human race.

[1] The *Origin of Species* appeared in November, 1859, but the first articles by Darwin and Wallace were read on July 1, 1858, and published by the Linnæan Society.

FIG. 787. — Collecting Devonian Fossils at Eighteen Mile Creek, western New York.

CHAPTER XXVII

A BRIEF SUMMARY OF THE CHARACTERS OF THE VARIOUS CLASSES OF PLANTS AND ANIMALS

BEFORE undertaking the study of the successive periods and eras in the history of the earth, the student should acquire some knowledge of the structure, mode of life, and distribution of the several classes of organisms with which we have to deal in the geological record. A course of study in general zoölogy and botany, and one in elementary palæontology, form a proper preparation for the study of earth history, but since such preparation is not acquired by all students of geology, the following brief summary is inserted. It should not, however, be regarded as a substitute for the more complete study of animal and plant life which all students of historical geology should undertake. When this is not done, however, the discussion in the present chapter should be supplemented by careful laboratory and museum work with recent and fossil organisms.

CLASSIFICATIONS OF ORGANISMS

The unit of organic life is the individual, and in the highest form of life, *i.e.*, mankind, each individual has its separate name. This consists of one or more given names, and the family name, the former identifying him as an individual, the latter as a member of a limited group, the family. A man might also be known as John Smith, Boston, Mass., U. S. A., which would further classify him as a member of a certain leading community, which itself is a unit within a larger commonwealth, which in turn is an integral part of a still larger community, that of the Usonians. If he is a descendant of the Mayflower group, he will probably regard himself as a typical and " original " American. It is on an analogous plan that animals and plants are classified, but the classification is not by community of association, but by community of descent or " blood relationship. "

Plants and animals represent the two organic *kingdoms*, and each kingdom is subdivided into large groups known as *phyla*, each of which contains a number of *classes*. The classes are again

FIG. 788. — Wharf piles at Vineyard Haven, Mass., overgrown with sedentary benthonic organisms. (Courtesy of the American Museum of Natural History.) A few of the organisms are exposed above water level. Different organisms cover the three piles; that on the left is covered mainly by ascidians and worm tubes, with a few sea-anemones. The middle pile has a larger number of sea-anemones, some contracted, others expanded. Mussels, barnacles, and other animals also occur. The broken pile on the right is thickly covered with mussels well seen in the lower part, while in the upper portion they are overgrown with hydroids, fully expanded. A few other animals also occur. All of these belong to the sedentary benthos. Vagrant benthonic animals are illustrated by starfish on the upper parts of the central and distant piles, and nektonic animals by the fish and the squid. A planktonic type is represented by the medusa or jelly-fish on the right.

divided into *orders* and the orders into *families*. Each family (which is a much larger assemblage than the human family, holding more nearly the numerical position of the human clan) contains one or many *genera* (singular *genus*), and each genus contains one or more *species*. The species, in turn, may have many *varieties*, and there is usually a vast number of *individuals*. It is obviously impossible to name each individual, when it is recognized for

FIG. 789. — Near view of a part of the underwater portion of the group of wharf piles at Vineyard Haven, Mass., shown in the preceding view, to bring out the detail of the animal life; taken from a slightly different angle. (Courtesy of the American Museum of Natural History.)

example that there are more than 384,000 living species of the single class of insects, some of those species with individuals beyond

FIG. 790. — Part of a rocky tide-pool at East Point, Nahant, showing its plant and animal life at low tide. From the life-size model in the American Museum of Natural History by courtesy of that institution. The overhanging rock ledge is thickly covered with small barnacles and the sides with mussels (*Mytilus*). A small group of the little sea snail (*Pupura lapillus*) is seen among the seaweed on the left. The great mass of seaweed is the round stemmed rock-weed (*Fucus vesiculosus*), with clumps of Bryozoa attached to the lower portions, but some of the flat-stemmed *Ascophyllum* also occurs. On the floor of the cave are other seaweeds, especially the Irish Moss (*Chondrus crispus*). Sea anemones are seen in various stages of contraction in the background, and an expanded one in the foreground. Scattered over the floor are sea-urchins (*Strongylocentrotus dröbachiensis*) and starfish (*Asterias*).

human power of counting. Hence naturalists have limited their taxonomic efforts to the naming of species, and sometimes varieties, disregarding individual differences which, nevertheless, exist. A man may recognize and call by name his dog or horse among a thousand others, but no one will distinguish between two flies or mosquitoes of the same species, though a specialist may attempt

FIG. 791. — Section of a portion of the sea-bottom at Woods Hole, Mass., showing the manner in which annelids build their tubes in the muddy sand. Many worms, shells, fragments of crustacean skeletons (crab-claws, etc.), and other organic remains are buried in the mud, in position for fossilization. The surface of the sand is strewn over with shells of Mollusca, partly buried horse-shoe crabs, etc. Many of the small shells are inhabited by hermit crabs. A large live whelk (*Sycotypus*) is partly buried in the sand, while several fish and a scallop (*Pecten*) swim among the eel-grass. Foreground of full-size model of shallow water life. (Courtesy American Museum of Natural History.)

even this for particular purposes. All living human beings are classed in one genus, *Homo*, man, and one species, *sapiens*, the wise one, irrespective of color, form, or mental development, though there are some who would separate modern mankind not only into races but also into distinct species. Other species of man have existed in the past, such as *Homo neanderthalensis*, *Homo heidelbergensis*, etc., and even other genera of man-like creatures, such as *Eoanthropus* and *Pithecanthropus*, have lived on earth. Domestic animals, too, such as the dog, are classed as one species despite their vast differences, though if they existed in a state of nature, they would unquestionably be placed in separate genera.

In the naming of a species, the genus to which it belongs is given first, and the species next. The generic name is generally, though by no means always, derived from the Greek. It is always written with a capital initial. The species name is commonly derived from the Latin, and is reduced to the adjective form and made to agree in gender with the generic name. It should never be capitalized,

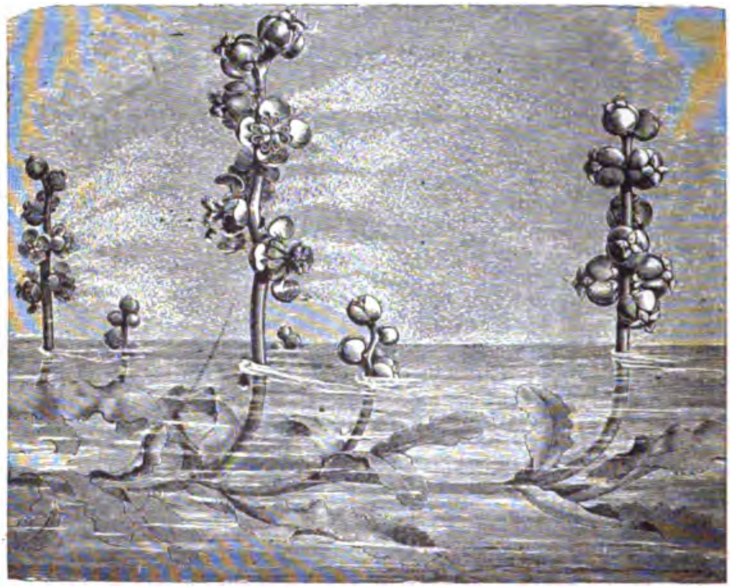


FIG. 792. — The Pondweed; a semi-aquatic plant with submerged leaves (*Potamogeton*). (From Ratzel.)

though some naturalists insist on doing so if the name is derived from a proper noun. Thus while *Heliophyllum halli* is the proper form, many prefer to write it *Heliophyllum Halli* because the specific name was given in honor of the palæontologist, James Hall. The name of the author of the species is generally placed after it in more or less abbreviated form. Thus *Atrypa reticularis*, Linn. means that Linnæus gave the specific name *reticularis* to that particular species of *Atrypa*, because of its reticulated surface ornamentation. The generic and specific names are always italicized in print.

The name of a family is derived from that of a prominent genus in the family, but the names given to higher divisions are independently derived. In the table of plants (p. 71), the phyla and classes only are given, but in that of the animals, smaller divisions are in some cases inserted.

Classification of Organisms according to Mode of Life

According to the conditions under which they live, plants and animals are classed as *aquatic* or *terrestrial*, depending upon whether they inhabit the water or the dry land (air). Aquatic forms may be further divided into marine, brackish-water, and fresh-water forms (Fig. 792). There are also a few animals which inhabit intensely saline brines, such as the brine shrimp (*Artemia salina*, Fig. 793 *a*).

Fig. 793 *a*. — The Brine Shrimp (*Artemia salina*). Side view, enlarged. (From Chambers' *Encyclopædia*.)

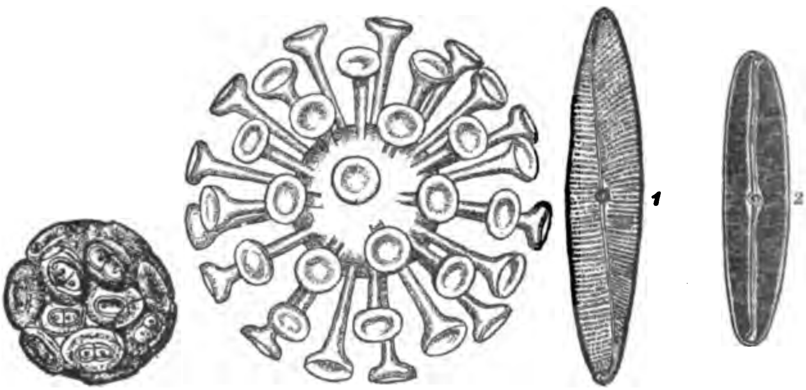
Aquatic forms may live upon the bottom of the sea or lake, or upon other organisms attached to the bottom. Such forms are called *benthonic* organisms (*benthos*) and they may be attached to the bottom, as are corals, sponges, seaweeds, etc. (*sedentary benthos*, Figs. 788–791), or move freely over it, as do many mollusks, starfish, crabs, etc. (*vagrant benthos*, Figs. 790, 791). Among animals there are a number of types such as fish, whales, squids, etc. which lead a perma-

Fig. 793 *b*.—The Portuguese man-of-war (*Physalia arethusa*). A floating (planktonic) colonial organism, with the variously modified members of the colony attached to a floating bladder (*pneumatophore*). Atlantic Ocean.

General Characters of the More Important Plant Types

Only a few of these groups of plants are of sufficient importance in the study of the past life of the earth to require a brief characterization.

Protophytes. — Of this phylum only the *bacteria* are of palæontological importance, for to this division probably belonged the earliest types of organisms. They consist of a single organic cell, which



A B C

Fig. 795. — Microscopic plants of the modern ocean. *A*, *Coccolithophore*, a protophyte covered with calcareous plates or coccoliths, greatly enlarged; *B*, *Rhabdosphere*, a protophyte covered with calcareous rods or rhabdoliths, greatly enlarged; *C*, Diatoms, or low algæ secreting silicious cases or frustules, greatly enlarged. 1, *Navicula jennii*; 2, *Navicula hibir*.

in the more primitive forms is without a nucleus. These organisms contain no leaf-green or chlorophyl, being able to produce their food in the dark. The lime-precipitating bacteria have already been referred to. Among the protophytes are also classed the coccolithophores, a group of marine planktonic algæ which secrete plates, disks, or rods of carbonate of lime (coccoliths, discoliths, rhabdoliths, etc.) which often play an important part in bottom deposits (Figs. 795 *A*, *B*).

Thallophytes. — The thallus plants are so called because they form an expansion or *thallus* of simple structure, not differentiated into root, stem, or leaf, although structures resembling these occur in the larger forms. They range from unicellular to multicellular types, and from microscopic size to the huge algæ of the

Pacific coast, which may grow to a length of several hundred feet. Three familiar groups are included here: (1) the *algæ* which develop leaf-green (chlorophyl) and live in the lighted zones of the sea and fresh water, (2) the *fungi*, without chlorophyl and which often grow in the dark (mushrooms, etc.), and (3) *lichens*, which consist of an intergrowth of algæ and

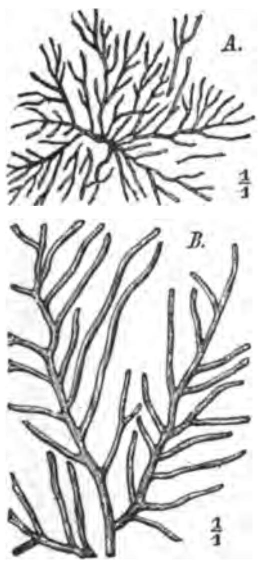


FIG. 796. — So-called Fucoids or "chondrites," believed to be sea-weeds or algæ. *A*, *Chondrites intricatus* of the Flysch (Oligocene), Swiss Alps; *B*, *C. targioni* (*C. bollensis*), Lias Württemberg. (After Steinmann.)

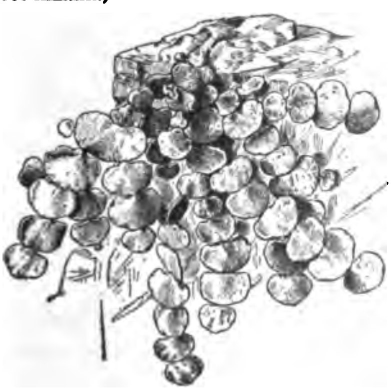


FIG. 797 *a*. — *Halimeda tuna*. A lime-secreting green alga or nullipore of the modern sea. (After Oltmanns.)

FIG. 797 *b*. — *Chara vulgaris*, a lime-secreting green alga of fresh-water ponds and lakes. (Haas.)

fungi and are capable of growing anywhere upon land, even in desert climates and upon barren rock surfaces.

The *algæ* are well represented in the rocks of the earth's crust, chiefly, however, by the lime-secreting forms (*nullipores*), which have already been described (Figs. 797 *a*, *b*, 803 *a*, *b*), and by the silica-secreting *diatoms* (Fig. 795 *C*). Many types of impressions upon rock surfaces have been interpreted as those of algæ and are

FIG. 798. — A modern green alga (dried specimen) (*Cladophora gracilis*). About twice natural size. (After Walcott.)

classed as *fucoids*, from the name of a common modern form, *Fucus*. Such markings are, however, often of mechanical origin. (Fig. 796 *A*, *B*.)

Modern algæ are divided into green, brown, and red algæ, according to the prevailing coloring matter present. Examples of the green algæ are the sea-lettuce (*Ulva*), the lime-secreting *Halimeda* (Fig. 797 *a*) which abounds on coral reefs, and the lime-secreting *Chara* (Fig. 797 *b*) of fresh water. The slimy pond scum also belongs here. A delicate filamentous marine form (*Cladophora*) is shown in Fig. 798. Brown algæ are represented by the common rock-weed (*Fucus*) of the Atlantic coast (Fig. 790), by the floating Gulf-weed (*Sargassum*) (Fig. 794), by the devil's apron-string

FIG. 799. — The Devil's Apron-String (*Laminaria*). A modern brown alga shown here growing on the bottom of the North Sea. It is wide-spread in the Atlantic. (From Ratzel, *Die Erde*.)

(*Laminaria*) (Fig. 799), and the large potash and iodine secreting kelps of the Pacific. They are often remarkably like land plants (especially the *Sargassum*), with a root-like " hold fast " and stem and leaf-like parts. Air bladders are common. The diatoms are also often classed here. The red algæ are mostly small, and range from bright to dark brownish red. The Irish moss (*Chondrus*),

Fig. 800. — Kelp gatherers, Cromarty, Scotland. The kelp is *Chondrus crispus* or Irish moss, which is sold in the markets. (Photo by author.)

Fig. 801. — A characteristic modern red alga (dried and pressed specimen, nearly natural size). (*Dumontia filiformis.*) (After Walcott.)

FIG. 802. — A modern red alga (dried specimen) and portion showing stem and branches (*Dasya gibbesii*). Twice enlarged. (After Walcott.)

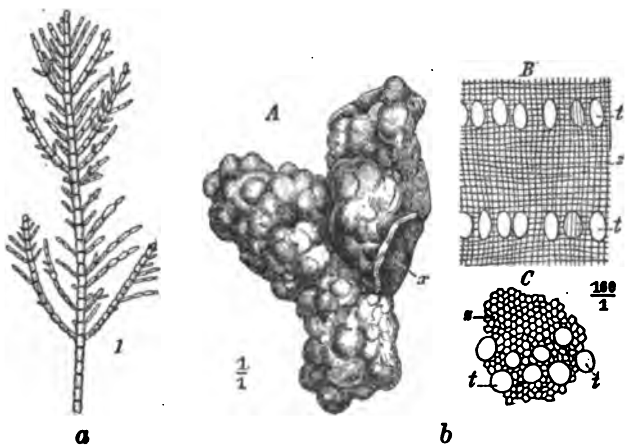


FIG. 803. — Lime-secreting red algæ. *a*, *Corallina* sp. from the modern sea. (After Oltmanns.) *b*, *Lithothamnium gosaviense* Cretaceous (Senonian) France; *A*, a knobby thallus, natural size; (*x*, place of attachment); *B*, longitudinal section × 160; *C*, transverse section × 160; (*z*, cellular tissue, *t*, tetrasporangia arranged in layers). (From Steinmann.) (See also Fig. 182, p. 272, Pt. I.)

often used for food, is an example (Fig. 800). Others are shown in Figs. 801, 802. A number of them secrete lime and are im-

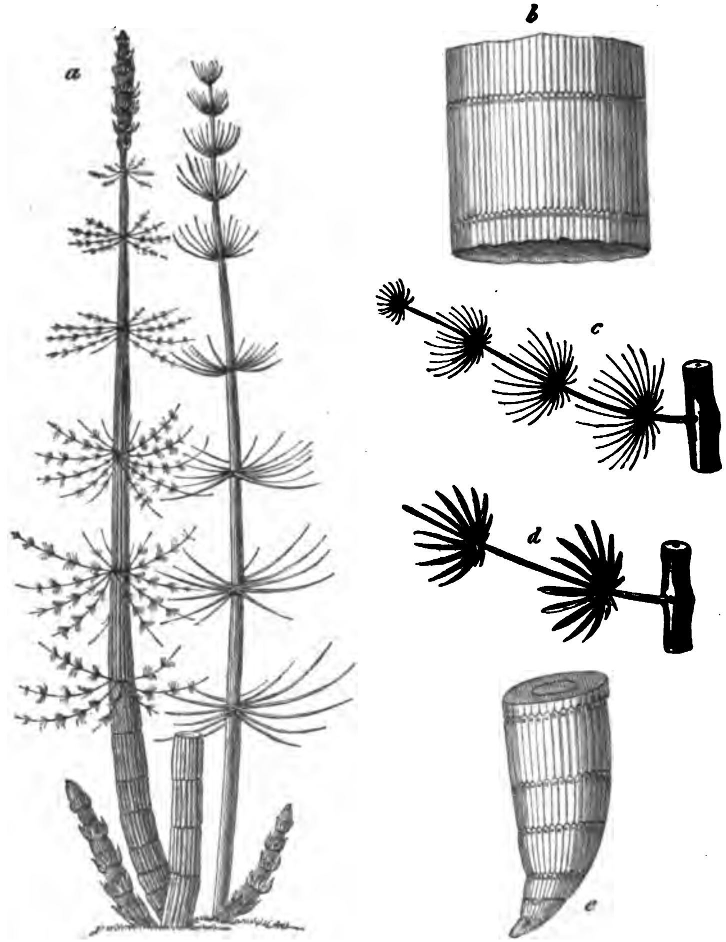


FIG. 804 *a–e*. — *Calamites*. *a*, hypothetical restoration of the tree; *b*, a portion of the stem; *c* and *d*, hypothetical twigs; *e*, lower end of the stem. (After Schenk.)

portant as rock formers (*Corallina*, Fig. 803 *a*, *Lithothamnium*, Fig. 803 *b*, etc.). They have already been discussed (p. 272, Pt. I).

Fungi and lichens are also found in some of the younger formations, but are difficult to recognize. Because of their ability to grow everywhere, lichens may have formed the primitive type of land vegetation during the earlier periods of the earth's history. Especially remarkable forms of lichens are the "hanging moss" (*Usnea*) of pine forests, the "reindeer moss" of the Arctic tundras, and the "manna lichen" of the Arabian Desert, the manna of the Israelites during the forty years of their wanderings.

Bryophytes. — These include the mosses and liverworts, which are all land plants, though some, like the peat moss (*Sphagnum*), grow

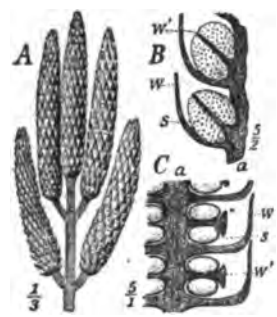


FIG. 804 *f.* — Fruitage of *Calamites*. *A*, *Calamostachys typica*, cones, one third natural size; *B*, *C. binneyanus*, section of part of cone × 5; *C*, *Palæostachys elongata*, section of part of cone × 2½; *w*, sterile bract; *w'*, fertile bract; *s*, sporangium or spore case. (From Steinmann.)

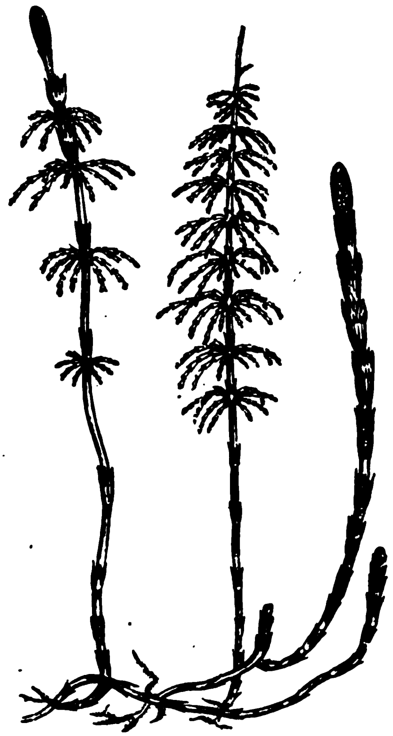


FIG. 805. — A modern horsetail or scouring-rush (*Equisetum arvense*). In the middle a sterile stalk; on left a fertile or spore-bearing stalk with branches; on right a spore-bearing one without branches. (From Haas, *Leitfossilien*.)

only on very wet surfaces. The plant consists of a stem with small leaves and root-like filaments (*rhyzoids*), but no true roots. They reproduce by spores. Fossil mosses are known from the Tertiary and doubtfully from the Mesozoic rocks.

Pteridophytes. — The fern plants are of great importance among the land vegetation of the past. Of the several classes the most important were the Equisetiæ, Sphenophylliæ, the lycopods and the ferns proper. The first were represented in the later Palæozoic by the giant *Calamites* (Figs. 804 *a–f*), which were trees sometimes reaching 60 meters in height. In structure they were like the modern horsetails (Fig. 805), small wood or wayside plants, but more complicated. The stem of the modern form is a

FIG. 806 *a*. — *Sphenophyllum schlotheimi*. A part of a stem with two whorls of leaves. (After Weiss.)

FIG. 806 *b*. — Fruitage of *Sphenophyllum angustifolium*. *A*, branch with leaves and two fruit cones, one half natural size; *B*, part of a cone enlarged twice; *a*, axis of cone; *w*, bracts (sterile); *s*, sporangium or spore case. (After Steinmann.)

hollow cylinder, arising from a prostrate root-stock or creeper. It is regularly jointed with whorls of slender leaves at the joints. Spore-

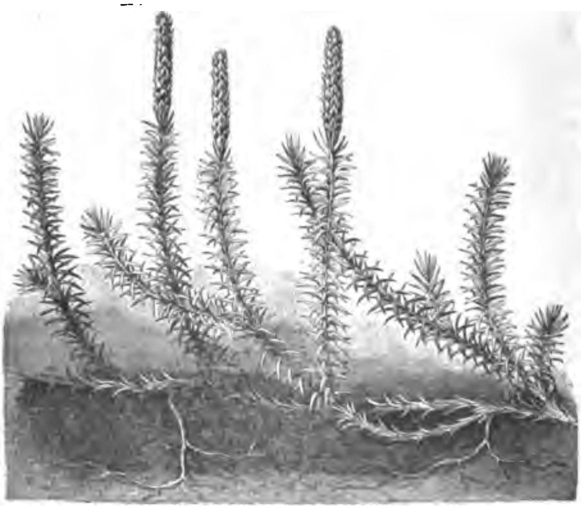


FIG. 807. — A modern lycopod (*Lycopodium annotinum*.) (After Kerner von Marilaun.)

bearing cones develop on separate plants or separate parts of the plant. Calamites are often preserved merely as stone molds of the interior hollow cavity of the stem and show a characteristic longitudinal fluting and cross-jointing.

Sphenophyllum is a slender twining form with whorls of wedge-shaped leaves. It is restricted to the Palæozoic (Figs. 806 *a*, *b*).

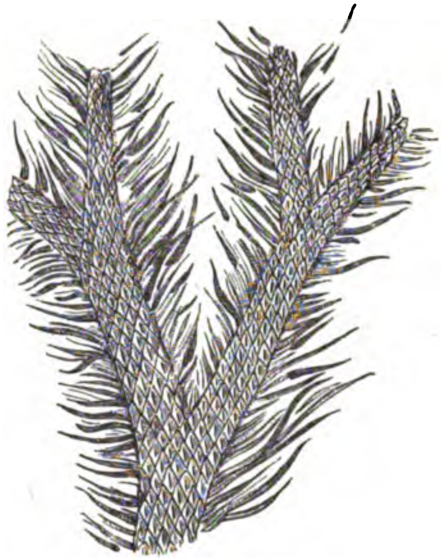


FIG. 808. — *Lepidodendron elegans.* Twig with leaves; reduced. (After Weiss.)

The *Lycopods* (Fig. 807) are familiar small woodland creepers resembling large mosses, and are extensively used for Christmas decorations. The stem arises from a creeping root-stock and has a central cylinder of woody tissue surrounded by bark, and bearing numerous small

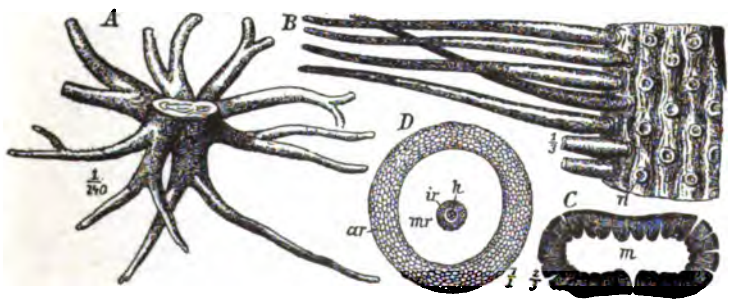


FIG. 809. — Root-stock of Palæozoic trees. (*Stigmaria ficoides.*) *A*, view of the numerous root-stocks proceeding from the stem, much reduced; *B*, part of a single root-stock (*stigmarium*) about one third natural size, showing a number of rootlets still adhering, and the scars (*n*) where others have dropped off; *C*, cross-section of a compressed stigmarium showing it to be a hollow wood cylinder; *m*, cavity formerly occupied by the pith, about two thirds natural size; *D*, section of a rootlet, enlarged seven times; *ar*, *mr*, and *ir*, outer, middle, and inner bark, respectively, *h*, woody cylinder. (After Steinmann.)

leaves. The spores are commonly formed on cones and are very numerous in modern forms, constituting the familiar lycopodium powder used in fireworks. The Palæozoic lycopods were mostly trees, varying in height up to 100 feet or more. Two principal types are recognized, (1) *Lepidodendron* (Fig. 808) with the surface of the stem covered with leaf scars marking the places from which the leaves have dropped and arranged in spiral forms outlined by diamond-shaped fields, and (2) *Sigillaria* (Fig. 1424 *b*) with the leaf scars arranged in vertical rows, generally separated by ridges. The rootstocks from which these trees arose are known as *Stigmaria* and are generally preserved as rock-filled cylinders covered with pits where the rootlets were attached (Fig. 809).

True ferns (Figs. 810 *a*, *b*), which reproduce by spores, also go back to the Palæozoic, but at that time a

FIG. 810 *a*.—A modern fern (*Polypodium vulgare*) entire plant. 1, piece of frond, showing sporangia; 2, a sporangium with its stalk magnified; 3, another one bursting and discharging its spores. (After Gray.)

FIG. 810 *b*.—Modern ferns. 1–3, *Dicksonia punctilobula;* 1, pinna; 2, portion of a pinnule enlarged; 3, a fruit dot in its cup-shaped indusium. 4–5, *Asplenium thelypteroides;* 4, a pinna; 5, part of a lobe in fruit, enlarged. (After Gray.)

FIG. 811. — A fossil cycad fern of the Coal-measures. (*Neuropteris heterophylla; A*, part of frond; *B*, a pinnule enlarged, showing the forked veins.)

FIG. 812. — Fossil ferns (cycad ferns) of the Coal-measures and Permian (*Rothliegendes*). *A*, *Callipteris conferta*, upper part of frond (Permian); *B*, *Callipteridium mirabile*, Coal-measures; *f*, triangular pinnules of rhachis; *C*, *C. pteridium*, a pinnule enlarged. (After Steinmann.)

FIG. 813. — Modern cycad trees. (*A*, *B*, *Cycas revoluta.*) ***A***, complete **female** (not cone-bearing) plant, about one-fiftieth natural size; *b*, fully developed fronds; *b'*, undeveloped (enrolled) fronds; *B*, end of stem of male plant with fronds cut away to show the terminal cone; one-fifth natural size; *bb*, bases of fallen fronds; *C*, *D*, Fructification of short-stemmed form (*Zamia integrifolia*, see also Fig. 814); *C*, single seed-bearing scale attached to the axis (*a*) seen from above, showing the two ovules, or seeds, characteristic of each scale; one-half natural size; *D*, cone of female plant showing the outer surfaces of close-set scales; one-third natural size. (After Steinmann.)

higher type of fern-like plants abounded, in which the reproductive parts had reached almost the complexity of the seeds in flowering plants. These are called cycad ferns (*Cycadofilicales*) and from them the cycads and the true flowering plants were probably derived. They belong properly in the next phylum. The simpler spore-bearing ferns, however, persist to the present time.

Fig. 814. — *Zamia spiralis*, a living cycad; southern Australia. (After Lyell.)

Spermatophytes. — The true seed plants, as distinct from spore plants, are represented in the Palæozoic by the cycad ferns, which are the more familiar "ferns" of the Coal-measure beds (Figs. 811, 812), and in the Mesozoic era by the cycads which still survive in the sago palm (Fig. 813) and others of that type. They develop thick, short stems (though some are tall) covered with leaf scales and crowned with fern-like leaves (Figs. 814, 815). The seeds are developed in cones similar to those of the pine, but in the Mesozoic forms (Fig. 816), which were for the most part in advance of the modern types, an organ closely resembling a flower was developed. A related form, but with broad, fan-like, undivided leaves, is the maidenhair tree or Ginkgo (Fig. 817), which was abundant in the Mesozoic, and has persisted to the present time. It has been in cultivation around the Japanese and Chinese temples since ancient days.

Fig. 815. — Frond of a fossil cycad (*Zamites feneonis*). Upper Jurassic; one-half natural size. (After Steinmann.)

The oldest coniferous trees (gymnosperms) are the cordaites (Fig. 818), the leaves and stems of which are common in the later Palæozoic deposits, after which they died out, having probably given rise to the ginkgoes. The leaves are often long and strap-shaped (sometimes exceeding eight feet in length), uniform, and situated at the tip of a stem, which

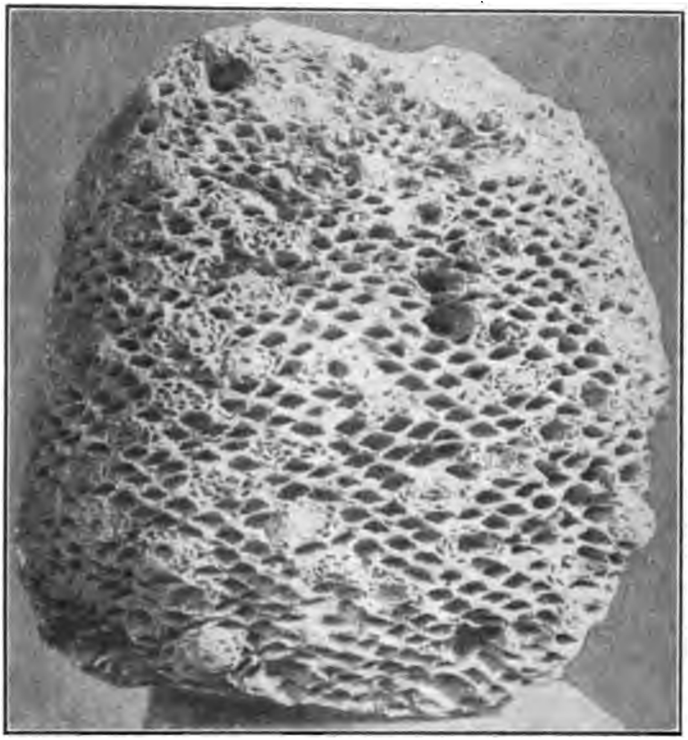


FIG. 816. — A fossil cycad trunk (*Tysonia marylandica*) from the Jurassic of Maryland; about one-fourth natural size. (After Fontaine, U. S. G. S.)

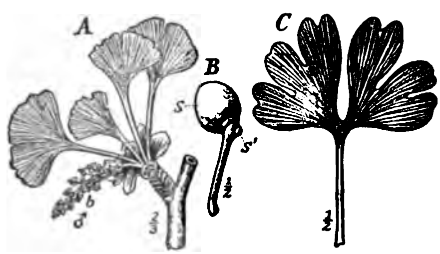


FIG. 817. — Branch and leaves of modern and fossil species of Ginkgo. *A*, *G. biloba*, the living species, branch with leaves and male flower (*b*) reduced; *B*, ripe seed of same (*s*) with an aborted seed (*s'*), one-half natural size; *C*, *G. huttoni*, leaf one-half natural size. Jurassic (Dogger). Yorkshire. (After Steinmann.)

sometimes grew to the height of 100 feet, and had a highly developed structure resembling that of modern conifers. The seeds were formed in cones and were not unlike those of the seed-ferns in complexity.

FIG. 818. — *Cordaites*, a characteristic late Palæozoic tree. *A*, restoration (with stem shortened) about $\frac{1}{250}$ natural size (more than 100 feet high); *B*, long strap-shaped leaf, natural size; *C*, broader and shorter type of leaf, one-third natural size; *D*, longitudinal section of male flower; *a*, axis; *br*, bracts; *bs*, petioles; *pl*, pollen sacs, enlarged $3\frac{1}{3}$ times; *E*, seed, one-half natural size; *G*, section of same, somewhat enlarged; *f*, outer fleshy, *h*, inner woody coating; *pk*, pollen chamber; *e*, endosperm; *F*, longitudinal and transverse section of a small stem; *m*, pith cylinder; *d*, diaphragm of same; *h*, woody cylinder; *v*, bark. (After Steinmann.)

Conifers of the modern type were abundantly developed in the Mesozoic and in the Cretaceous and Tertiary, when the great sequoias were widespread. Two species, *Sequoia gigantea* (Fig. 819) and the related redwood (*S. sempervirens*), still survive. The essential characters of the principal modern conifers are shown in Figures 820 to 823.

FIG. 819. — The giant sequoias or "Big Trees" (*Sequoia gigantea*) Mariposa, California.

FIG. 820. — The Spruce. (*Abies picea.*) 1, male flower; 2, female flower; 3, carpel leaf from above with the 2 seed buds × 2; 4, corresponding covering leaf × 2; 5, ripe cone; 6, scale of same viewed from above with the two winged seeds; 7, corresponding covering leaf; 8, branch with leaves (needles) and a few male flowers; 9, enlarged needle of seedling plant; 10, seedling with normal and reversed position of seed; 11, cross section of a needle × 7; (1, 2, 5 and 10 one-half natural size). (After Fischbach.)

The *Angiosperms* or true flowering plants, which at present comprise more than half of all known plants, first became prominent in the later Mesozoic (Cretaceous). It was at this time that insects first became an important element of the land faunas, and it has been thought that this was a potent factor in the rapid rise of flowering plants. For such plants depend largely upon insects

FIG. 821. — The Fir (*Abies pectinata*). 1, Male flower; 2, female flower; 3, scale of same; 4, carpel leaf with 2 seed buds × 4; 5, scale of cone seen from below, with covering leaf when ripe; 6, mature seed with 2 wings; 7, mature cone; 8, axis or spindle of denuded cone; 9, branch with needles; 10, seedling plant in autumn of first year. (All except No. 4 one half natural size.)

to carry the pollen from flower to flower and so effect fertilization, whereas the older types of plants, including the conifers, have their pollen transported by wind, and fertilization is a less certain process. Flowering plants now cover the surface of the earth nearly everywhere, and have even ventured into the water, as rushes and water lilies in ponds, and as eel-grass and mangrove in the sea. See Figs. 274, p. 330, and 284, p. 340, Pt. I.

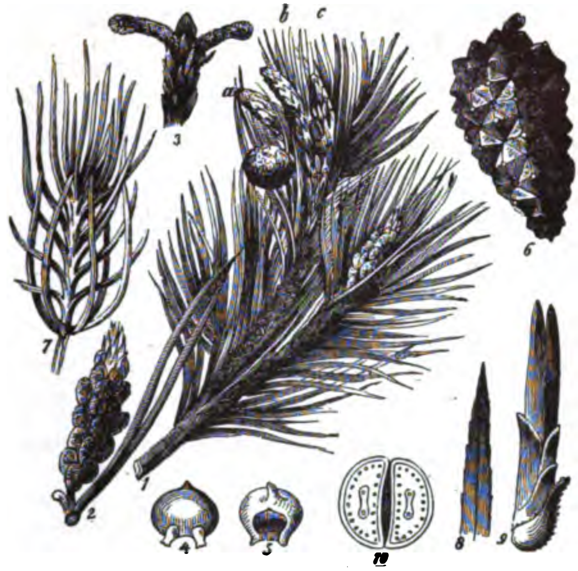


FIG. 822. — The Pine (*Pinus sylvestris*). 1, Branch with needles and flowers; 2, male flower; 3, female flower; 4, carpel from above with two seed buds; 5, the same from below, with covering leaf; 6, mature cone; 7, seedling plant with cotyledons and simple leaves; 8, one of the seedling leaves enlarged; 9, double needle in developmental stage; 10, transverse section of two mature needles. 1, 2, 3, 6, one-half natural size; 7, natural size; others enlarged from 5 to 8 times. (After Fischbach.)

FIG. 823. — The Larch (*Larix europœa*). 1, Branch with (*a*) male, (*b*) female flowers × ½; 2, female flower, natural size; 3, carpel with seed buds × 3; 4, cover of same × 3; 5, mature cone × ½; 6, scale with covering leaf still intact, natural size; 7, the two seeds of a scale × ½; 8, leaf of seedling plant × 5. (After Fischbach.)

Animals

The following table gives the phyla and classes of animals living and extinct.

Subdivisions of the Animal Kingdom

Phylum XI. — *VERTEBRATA.*

Class 6. *Mammalia*, or mammals (including man).
Class 5. *Aves*, or birds.
Class 4. *Reptilia*, or reptiles.
Class 3. *Amphibia*, or amphibians.
Class 2. *Pisces*, or fishes.
Class 1. *Ostracoderma*, or ostracoderms.

Phylum X. — *PROTOCHORDATA* (*Amphioxus*, ascidians, *Balanoglossus*, etc.).

Phylum IX. — *ECHINODERMATA.*

Class 7. *Holothuroidea*, or holothurians.
Class 6. *Echinoidea*, or sea-urchins.
Class 5. *Asteroidea*, or star-fish.
Class 4. *Ophiuroidea*, or brittle-stars.
Class 3. *Crinoidea*, or crinoids.
Class 2. *Blastoidea*, or blastoids.
Class 1. *Cystoidea*, or cystoids.

Phylum VIII. — *ARTHROPODA.*

Class 5. *Hexapoda*, or insects.
Class 4. *Acerata*, or spiders, scorpions, merostomes.
Class 3. *Crustacea*, or lobsters, crabs, Entomostraca, barnacles, ostracods, trilobites, etc.
Class 2. *Myriopoda*, or centipedes, millepedes.
Class 1. *Protarthropoda* (*Peripatus*).

Phylum VII. — *VERMES*, or worms. A heterogeneous group including at present some unrelated forms and divided into eight classes and many subclasses.

Phylum VI. — *PLATYHELMINTHA*, or flatworms including planarians, tapeworms, etc.

Phylum V. — *MOLLUSCA.*

Class 7. *Cephalopoda*, including the subclasses Dibranchiata (squids, octopus, belemnites, etc.) and Tetrabranchiata (ammonoids and nautiloids).
Class 6. *Pteropoda*, or pteropods.
Class 5. *Conularida* (*Conularia*, *Hyolithes*, *Tentaculites*, etc.).
Class 4. *Scaphopoda* (*Dentalium*, etc.).
Class 3. *Gastropoda*, or gastropods, snails.
Class 2. *Amphineura* (*Chiton*, etc.).
Class 1. *Pelecypoda*, or lamellibranchs or bivalves.

Phylum IV. — *MOLLUSCOIDEA.*

Class 2. *Brachiopoda*, or brachiopods.
Class 1. *Bryozoa*, or Polyzoa (moss-animals).

Phylum III. — *CŒLENTERATA.*

Class 6. *Ctenophora*, or comb-bearers.

Class 5. *Anthozoa*, coral polyps, including four orders Octoseptata, Hexaseptata, Tetraseptata and Aseptata.

Class 4. *Scyphomedusæ*, including the larger jellyfish.

Class 3. *Hydromedusæ*, or hydroids and smaller jellyfish.

Class 2. *Graptozoa*, or graptolites (extinct).

Class 1. *Hydrocorallinæ* (including the modern millepores and the extinct stromatoporoids).

Phylum II. — *PORIFERA* (Sponges).

Class 5. *Calcarea*, or calcareous sponges.

Class 4. *Myxospongida.*

Class 3. *Triaxonida*, or Hexactinellidæ.

Class 2. *Tetraxonida.*

Class 1. *Euceratosa*, or horny sponges, including the common bath sponge.

Phylum I. — *PROTOZOA* with numerous classes including the calcareous-shelled *Foraminifera* and the silicious-shelled *Radiolaria*, which are the only ones known in a fossil state.

Essential Characters of the More Important Types of Animals

A brief characterization of the more important classes may be given.

Protozoa. — These are all single-celled animals of simple organization though complex constitution. Protozoa were probably the first animals in the world, but these Protozoa were of much simpler and more primitive structure than their modern descendants. The common modern fresh-water *Amœba* (Fig. 824) illustrates the essential characters of the animal. Most members of the class Foraminifera build calcareous shells; some build them after they have attained full growth, but others begin early. As a result, on further growth of the animal, the shell is too small and a part of the soft tissue lies outside of it. This is then surrounded by shelly matter forming a new chamber.

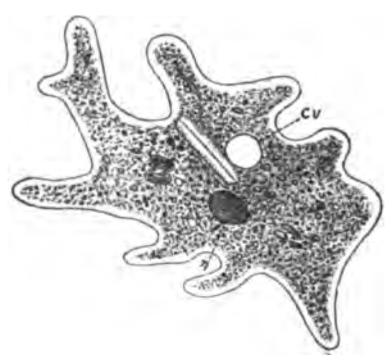


FIG. 824.—*Amœba proteus*, Ehr. A modern shell-less protozoan. *n*, nucleus; *cv*, contractile vacuole. A large ingested diatom is seen. Greatly enlarged. (From Conn.)

Some Foraminifera have few chambers, others very many, depending on the relative rate of growth and shell building. Many foram-

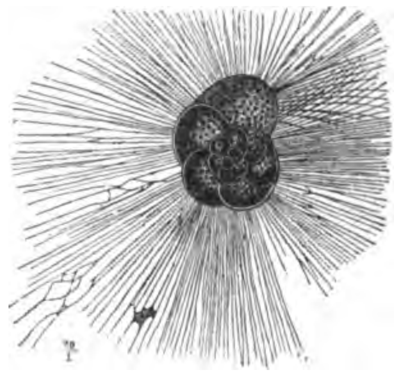


FIG. 825. — A typical perforate Foraminifer (*Rotalia*) with expanded pseudopodia. Recent. Enlarged 20 times. (After Steinmann.)

iniferal shells are pierced by numerous hóles (*Perforata*) through which the organic matter projects as threads (*pseudopodia*, Fig.

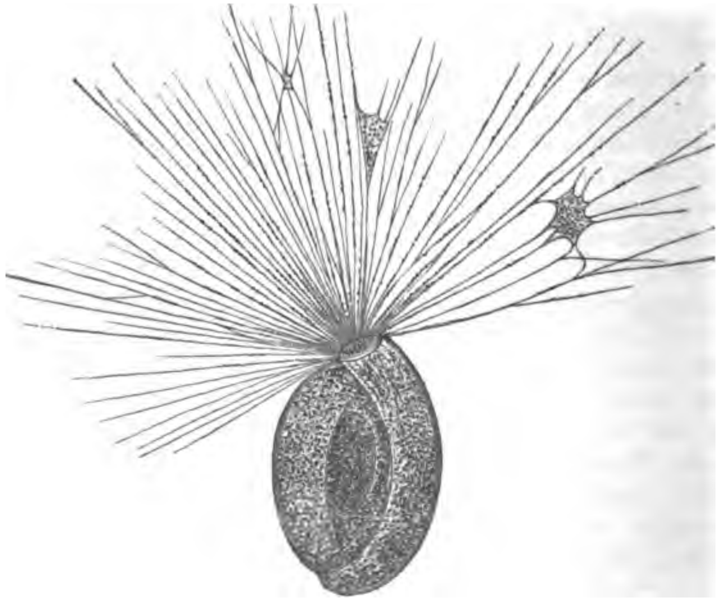


FIG. 826. — *Miliola tenera*. A modern Foraminifer of the imperforate type, with extended fleshy pseudopodia only from the terminal aperture. (Compare with *Globigerina*, Fig. 195, Pt. I.) Important as a limestone builder. (From Haas' *Leitfossilien*.)

825; see also Figs. 195, 196, p. 275, Pt. I); others (*Imperforata*, Fig. 826) are without these pores, from which, however, the class derives its name. The rock-building work of these shells has already been noted (p. 276, Pt. I). All shell-building Foraminifera are marine, either plankton or vagrant benthos. The Radiolaria are marine planktonic Protozoa which secrete an internal silicious structure, often of great delicacy and beauty (Figs. 827, 1–5). These shells form an important source of silica in the

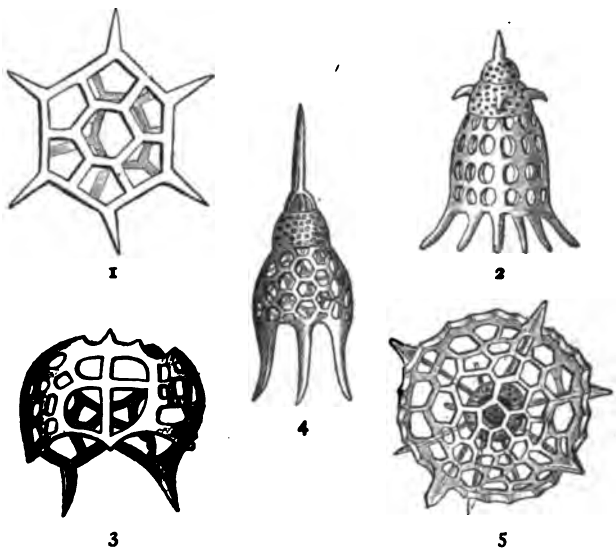


FIG. 827. — A group of Radiolaria. 1, *Distephanus rotundus;* 2, *Pterocodon campana*, Tertiary, Barbadoes; 3, *Petalospyris corona*, from tripolite of Grotte; 4, *Podocystis schonsburghi*, Tertiary, Barbadoes; 5, *Actinomma schwagerís*. From tripolite of Grotte.

marine sediments from which subsequent structures (concretions, etc.) are made by segregation.

Porifera (Sponges). — Most modern sponges are colonial animals attached to the sea bottom, though a few also occur in fresh water. In its simplest structure, a sponge consists of a central cavity surrounded by fleshy matter in which there are many canals and pores to permit the water to enter and bring in food. This, in primitive forms, is digested in the central cavity, but in others, in secondary cavities surrounding the central one (Figs. 828–830). The water and undigested food are carried out through the terminal orifice or

osculum of the central cavity. The flesh is strengthened and supported by a meshwork of horny, silicious or calcareous fibers, more or less united into a solid mass (Fig. 830). This, in the horny sponges, forms "the sponge" familiar to all, but it must be remem-

FIG. 828. — A simple modern sponge (*Ascetta primordialis*). (After Haeckel.)

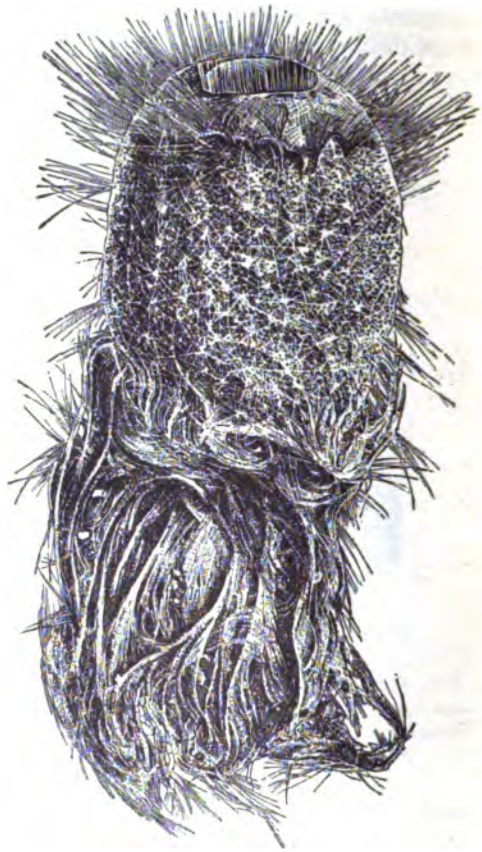


FIG. 829. — A modern complex silicious sponge (*Holtenia carpenteri*), with the body strengthened by silicious rods and spicules and long basal fibers of silica, used for fixation.

bered that the organic matter has all been removed. In such a sponge a number of tube-like central cavities may generally be seen, each terminating in a large round osculum (Fig. 830, *a*). In some horny sponges silicious rods or spicules are present, while in silicious sponges they predominate, forming a rigid silicious structure by the union of their ends (Figs. 831 *a*, *b*). In still other sponges this material is carbonate of lime. Such sponges often re-

FIG. 830. — Skeleton of a modern tetractinellid sponge (*Caminus vulcani*) from the Adriatic Sea, with section. *a*, oscula or excurrent apertures; *b*, central cavity (paragaster); *c*, dermal layer; *d*, external pores (ostia) which admit the water, which is carried by canals (epirrhiza) to the digestive chambers and thence by other canals (aporrhyza) to the central cavity (paragaster) and out by the osculum. (From Steinmann.)

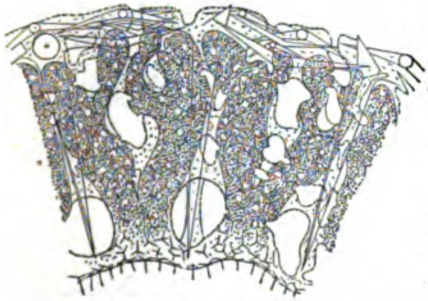


FIG. 831 *a*. — Part of transverse section of a modern sponge (*Heteropegma nodus-gordii*), showing location of spicules. (After Polejaeff, *Challenger Report*.)

FIG. 831 *b*. — Part of the skeletal structure of a silicious sponge (*Jereica polystoma*) formed by the union of the spicules.

tain their form in great perfection when fossilized (Fig. 270, p. 326, Pt. I). Types of spicules of modern sponges are shown in Fig. 832.

Cœlenterata (Hydroids, corals, etc.). — In the simplest living cœlenterates, the hydroids, the animal polyp consists of a hollow central cavity, the stomach, enveloped by a double-layered wall

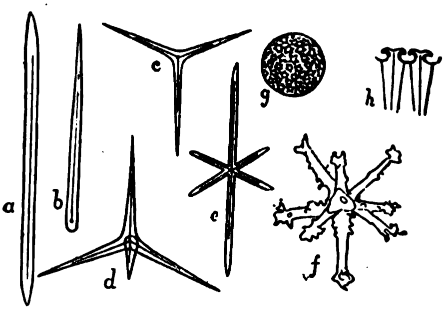


FIG. 832. — Typical forms of sponge spicules (*Megascleres*).

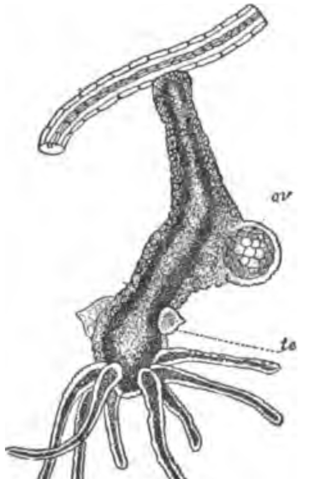


FIG. 833. — *Hydra viridis;* this common fresh-water hydroid suspended from a plant filament; much enlarged. (After Lankester.) *ov*, ovary; *te*, testis.

FIG. 834. — Portion of a colony of a modern marine hydroid (*Bougainvillea fruticosa*), showing the polyps and medusæ. (After Allmann.)

with a single orifice, the mouth, which is surrounded by tentacles. These are commonly furnished with peculiar stinging cells for paralyzing their prey.

Hydra (Fig. 833), the simplest form, lives in fresh water, but most types are marine and are compound, many polyps being

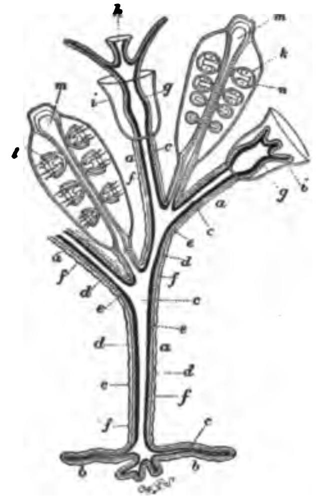


FIG. 835. — Diagram of a hydroid. *a*, hydrocaulus; *b*, hydrorhiza (root); *c*, enteric cavity; *d*, endoderm; *e*, ectoderm; *f*, perisarc (horny covering); *g*, expanded hydranth or polyp; *h*, hypostom with mouth at extremity; *i*, hydrotheca; *k*, sporosac; *l*, medusiform person springing from *m*; *m*, a modified hydriform person or blastostyle; *n*, horny case or gonangium enclosing blastostyle and its buds.

FIG. 836. — Small portions of the branches of modern hydrozoans; enlarged views of thecæ. *A*, *Plumularia pennatula* enlarged, showing single row of hydrothecæ; *B*, *Sertularia fallax*, enlarged, showing double row of hydrothecæ; *C*, same, showing egg capsule. (After Johnston.)

united by tubes or hollow stems resembling the stalks of flowers (Figs. 834–835). Some polyps become specially modified, forming buds, which often break away and become free-swimming jelly-

FIG. 837. — Developmental stages in the common jellyfish *Aurelia*. 1, free-swimming embryo; 2, embryo settled down; 3–6, stages in the development of the asexual hydroid stage; 7–8, transverse budding of hydra producing succession of individuals; 9, liberation of individuals; 10, 11, steps in development of free medusa. (After Haeckel.)

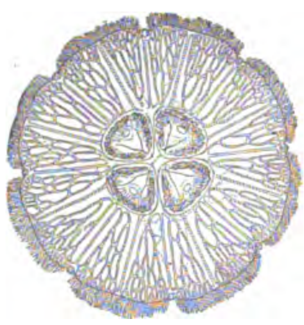


FIG. 838 *a*. — The common white jellyfish (*Aurelia flavidula*). Upper side, about one fifth natural size. Atlantic coast. (After Verrill and Smith.)

FIG. 838 *b*. — A jellyfish (*Dactylometra quinquecirra*) side view, about one fifth natural size. Atlantic coast. (After Verrill and Smith.)

fish. In other cases, the entire polyp breaks into a succession of disks, each of which grows into a jellyfish (Scyphomedusæ) (Figs. 837–838 *b*). Most marine hydroids become enveloped in a sheath

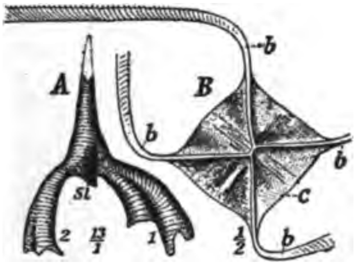


FIG. 839. — Structure of Ordovician graptolites. *A*, *Didymograptus minutus*, sicula and the early hydrothecæ, enlarged thirteen times; *B*, *Dichograptus headi*, central disk (*c*), with four branches of hydrothecæ (*b*); one half natural size. (From Steinmann.)

or coating of chitinous material, often ending in a cup around each polyp into which it can withdraw on disturbance. These chitinous coverings, alone, are preserved. In the extinct group of *graptolites*

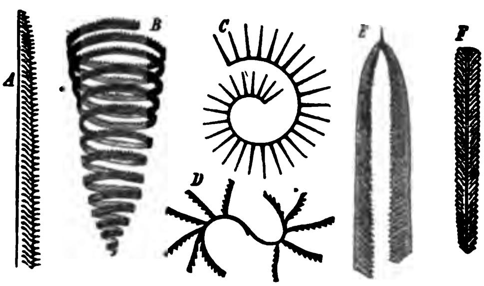


FIG. 840. — Types of graptolites. *A*, *Monograptus colonus*, Silurian; *B*, *M. turriculatus*, Silurian; *C*, *Rastrites linnii*, Silurian; *D*, *Cœnograptus gracilis*, Ordovician; *E*, *Didymograptus murchisoni*, Ordovician; *F*, *Diplograptus palmeus*, Silurian.

a succession of cylindrical or cornucopia-shaped cups is formed by budding one from the other, either in a single or in a double row (Fig. 839), and when these are flattened on fossilization, they have the appearance of the teeth of a fine saw (Figs. 840 *A–F*). When the tubes occur in a double row, they are often strengthened by a rod of horny material (the *virgula*) between the rows (Fig. 841). In one group (*Monograptidæ*, Figs. 842 *A–D*) characteristic of the Silurian, a single row of cups is thus strengthened. Some hydroids build horny incrusting layers above which the soft bodied polyps project (*Hydractinia*, Figs. 843, 844), and others again form

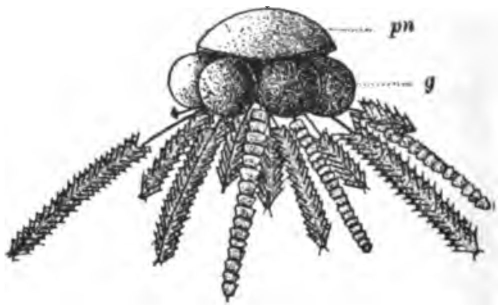


FIG. 841. — A graptolite colony (*Diplograptus*), restored. (After Ruedemann.) *pn*, floating bladder (pneumatophore); *g*, reproductive sacs (gonangia).

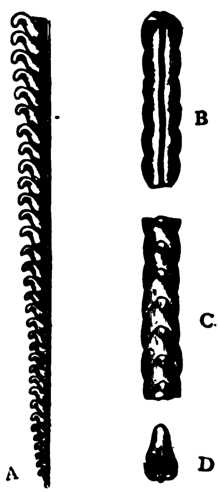


FIG. 842. — *Monograptus priodon*, preserved in relief. *A*, lateral view, slightly enlarged; *B*, dorsal view of a fragment considerably enlarged; *C*, front view of fragment, showing mouths of hydrothecæ, much enlarged; *D*, transverse section of same. Silurian. England.

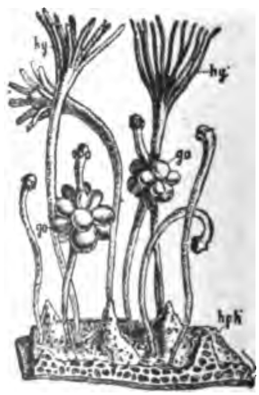


FIG. 843. — *Hydractinia echinata*, a modern hydroid of the North Atlantic; enlarged. The various polyps arise from a fleshy carpet, the *cœnosarc hph'*, which builds a chitinous meshwork, generally overgrowing molluskan shells, and the surface of which rises in spiny elevations; *hy*, feeding polyps (*hydropolyps*); *go*, reproductive polyps (*gonopolyps*); long slender "fighting polyps" furnished with stinging cells (nettle-cells) are also shown. (From Steinmann.)

calcareous structures instead of horny coverings. This is the case in the genus *Millepora* of modern coral reefs (Figs. 845, 846) and in the extinct *Stromatopora* in which a succession of concentric

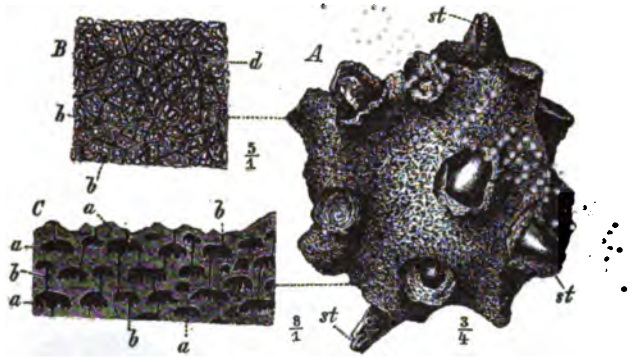


FIG. 844. — *Hydractinia incrustans.* A Pliocene species enveloping a gastropod shell (*Purpura*), the spines of which (*st*) are exposed by removal of the hydroid incrustation; three fourths natural size. *B*, part of the surface enlarged five times, showing zooidal types, occupied by the polyps, and a network of surface canals (*sarkorchiza*); *C*, transverse section; *a*, interlaminar spaces; *b*, openings of zooidal tubes. (After Steinmann.)

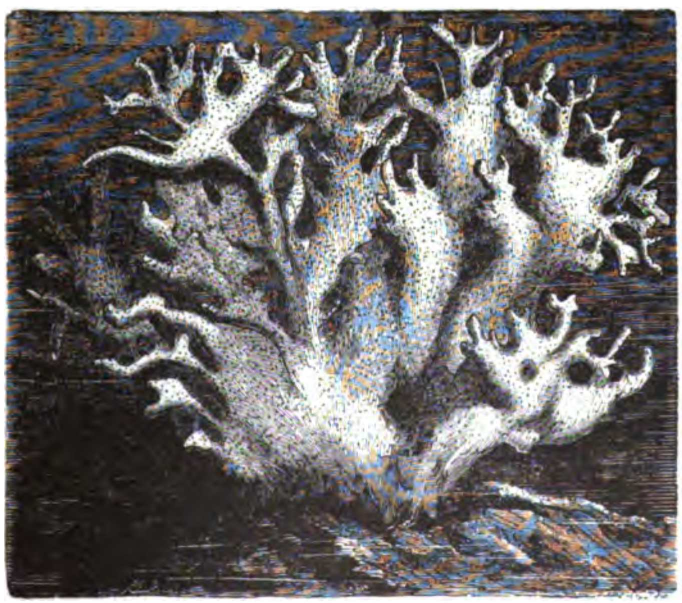


FIG. 845. — *Millepora alcicornis.* A modern hydrocoralline. (From Dana's *Corals and Coral Islands;* by permission of Dodd, Mead and Co.).

layers of lime were deposited, each layer with a definite cellular structure (Fig. 847).

Anthozoa. — The only other Cœlenterata of importance to the geologist are the Anthozoa or coral polyps, which are all marine. The coral polyps differ from the hydroid polyps in the inturning or invagination of the mouth region, so that a sac-like body hangs inward below the new mouth, which is surrounded by the edge of

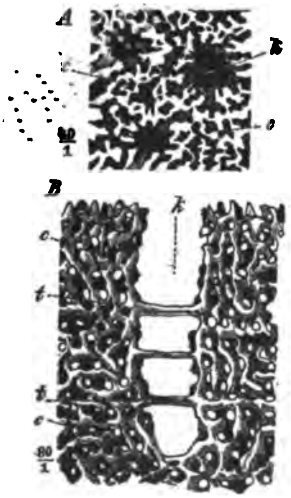


FIG. 846. — Surface view (*A*) and longitudinal section (*B*) of a portion of the hydrocoralline skeleton (*Millepora nodosa*), both greatly enlarged; *c*, cœnenchyma with fine irregular tubes opening in small surface pores (dactylopores); *k*, tubes occupied by main polyps (gastropores); *t*, horizontal partitions or tabulæ cutting off the older unused portions of the tube. (From Steinmann.)

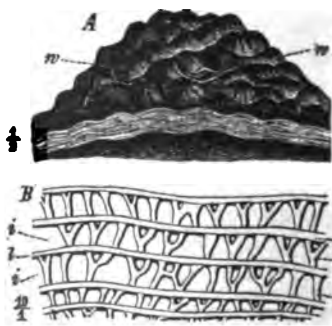


FIG. 847. — General view and section of characteristic Palæozoic stromatoporoids. *A*, *Actinostroma verrucosum*, Devonian, with polished edge showing structure × ½; *w*, mammilar surface elevations with branching canals (astrorhiza); *B*, *Clathrodictyum striatellum*, Silurian, × 10; *l*, horizontal laminæ; *p*, vertical elements or pillars; *i*, interlaminar spaces. (After Steinmann.)

the inturned portion, while the opening at the bottom of the sac (*stomodæum*) corresponds to the mouth of the hydroid polyp. This relationship is shown in the following diagrams (Fig. 848).

The interior of the body (stomach cavity), except this stomodæum, is further divided into radial compartments by pairs of fleshy septa or mesenteries, and in general each compartment is drawn out into a hollow tentacle (Fig. 849). Some polyps (sea-anemones, Fig. 850) do not secrete hard structures, but most of them do. These coral structures have already been described (p. 282, Pt. I); they consist essentially of a series of radiating plates or *septa* surrounded or connected by a wall at their outer ends.

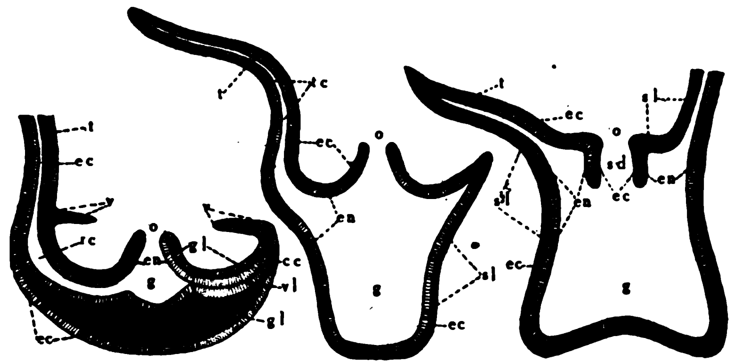


FIG. 848. — Diagrammatic longitudinal sections of (*a*) craspedote medusa, (*b*) hydroid polyp, and (*c*) coral polyp. *cc*, circumferential canal (in medusa); *ec*, ectoderm; *en*, endoderm; *g*, gastric cavity; *gl*, jelly-like layer between endoderm and ectoderm (in medusa); *o*, oral aperture or mouth; *rc*, radiating canal; *sd*, stomodæum or œsophagus; *sl*, supporting lamella or mesoglœa; *t*, tentacles; *tc*, tentacular canal; *v*, velum (in medusa); *vl*, vascular lamella, or cathammal plate (in medusa). (Original.)

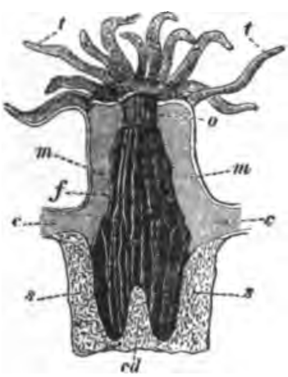
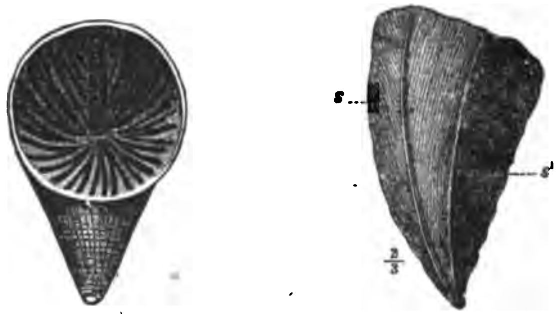


FIG. 849. — Longitudinal section of a coral polyp (*Astroides calycularis*) from the Mediterranean; *s*, *cd*, stony corallum; *s*, septum; *cd*, columella; *m*, mesenteries; *c*, cœnosarc; *f*, intermesenterial chambers; *o*, stomodæum; *t*, tentacles. (After Steinmann.)

FIG. 850. — *Actinoloba* (*Metridium*) *marginata*, the common sea anemone of the North Atlantic.

In one group (*Tetraseptata*), in which the septa are built on the plan of four, they begin as ridges on the inside of a cup formed of a succession of calcareous rings (*epitheca*), and with further growth meet



a *b*

FIG. 851. — Palæozoic tetraseptate corals. *a*, *Zaphrentis*, showing the arrangement of the septa in the calyx, and their relation to the cardinal septum in the center; *b*, side view of *Streptelasma*, showing the arrangement of the septal grooves, or outer margins of the septa; *s*, cardinal septum; *s'*, one of the alar or side septa. Note the pinnate arrangement of the septa of the cardinal quadrants on both sides of the cardinal septum, and the similar arrangement of the septa in the counter quadrants on one side of the alar septum. (After Steinmann.)

FIG. 852. — A compound tetraseptate Palæozoic coral (*Acervularia*, partly worn), showing the crowded prismatic tubes, with the septa limited on the interior by an inner wall. (Kayser.)

FIG. 853. — Fragment of a compound aseptate Palæozoic coral (*Favosites*), showing the fine closely crowded prismatic tubes, and a portion of these tubes enlarged, showing the double row of "mural pores" on each face, and (where broken) the transverse plates, or "tabulæ" and absence of septa.

in the center (Figs. 851 *a, b*). This group is largely confined to the Palæozoic, and for the most part consists of single, horn-shaped individuals, though sometimes by the budding of several new ones from the margin of the parent, a compound form is produced, the individuals remaining round, if loosely grouped, or becoming

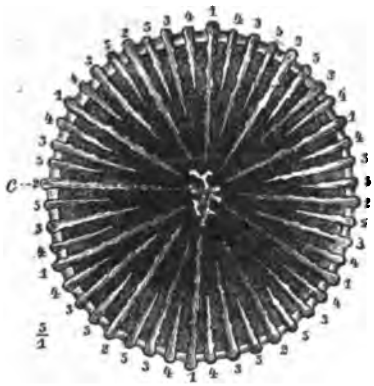


FIG. 854. — Calyx view of a modern hexaseptate coral (*Parasmilia*). 1, First; 2, second; 3, third; 4 and 5, fourth cycle of septa; *c*, spongy columella. Note that the septa project beyond the outer wall or theca, forming "costæ." (From Steinmann.)

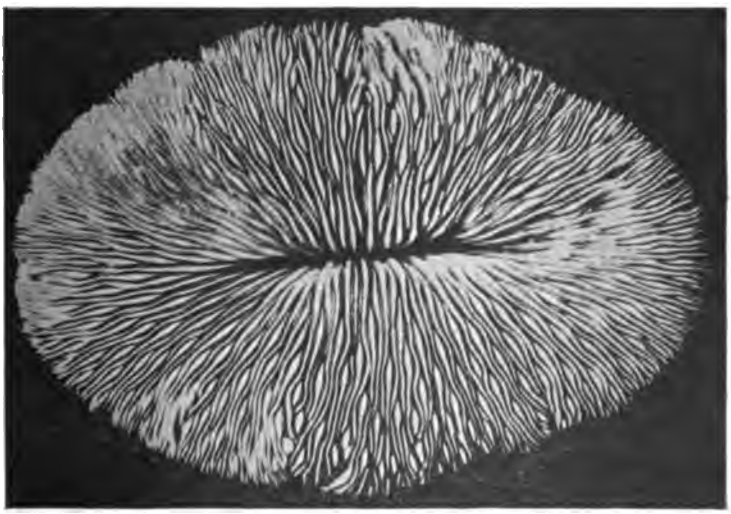


FIG. 855 *a*. — *Fungia scutaria* Lamarck. Upper surface. (After Vaughan.) One of the large single corals living free upon the surface of modern coral reefs. (× $\frac{5}{8}$.)

prismatic (usually of six-sided section) if crowded (Fig. 852). A second group, also confined to the Palæozoic, consists chiefly of the wall with the septa reduced to spines or absent altogether

(*Aseptata*). In their place are many transverse floors (*tabulæ*) which cut off the older portion. These forms are generally closely

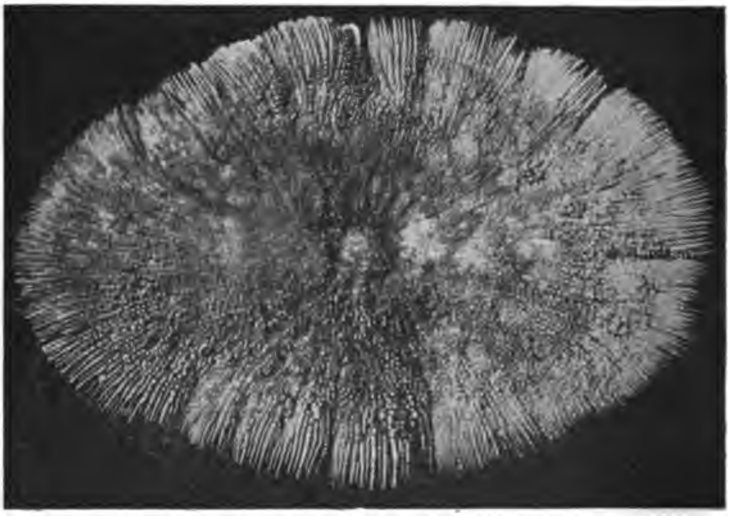


FIG. 855 *b*. — *Fungia scutaria* Lamarck. Lower surface of the same specimen. (After Vaughan.) ($\times \frac{5}{8}$.)

crowded from rapid budding, and so each corallite becomes a slender prism. In the walls of this prism are many pores, the records of unsuccessful budding (Ex. *Favosites*, Fig. 853). A third group

FIG. 856 *a*. — *Caryophyllia alcocki* Vaughan. Modern deep sea coral, side view, natural size. (After Vaughan.)

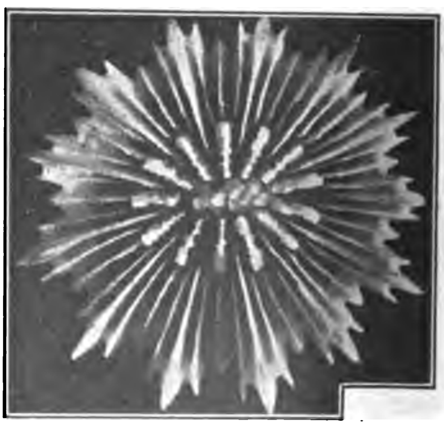


FIG. 856 *b*. — *Caryophyllia alcocki*. Calyx enlarged $\times 2\frac{1}{2}$. (After Vaughan.)

FIG. 857. — *Leptastrea purpurea.* A compound corallum, the calices united by their costæ, with new buds appearing at the junction point of three or more calices. Enlarged four times. (After Vaughan.)

FIG. 858. — *Goniastrea pectinata.* A compound corallum, with angular calices joined by their walls, and increasing by division of the older ones. Enlarged four times. (After Vaughan.)

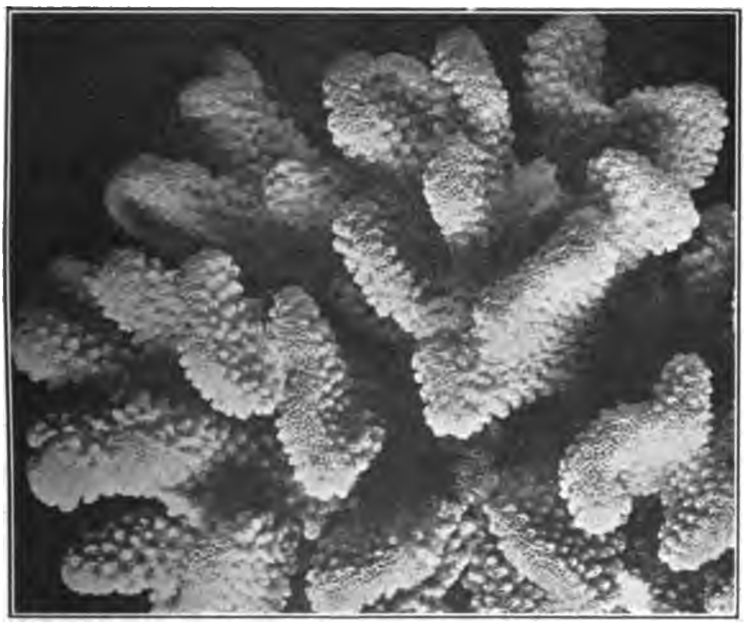
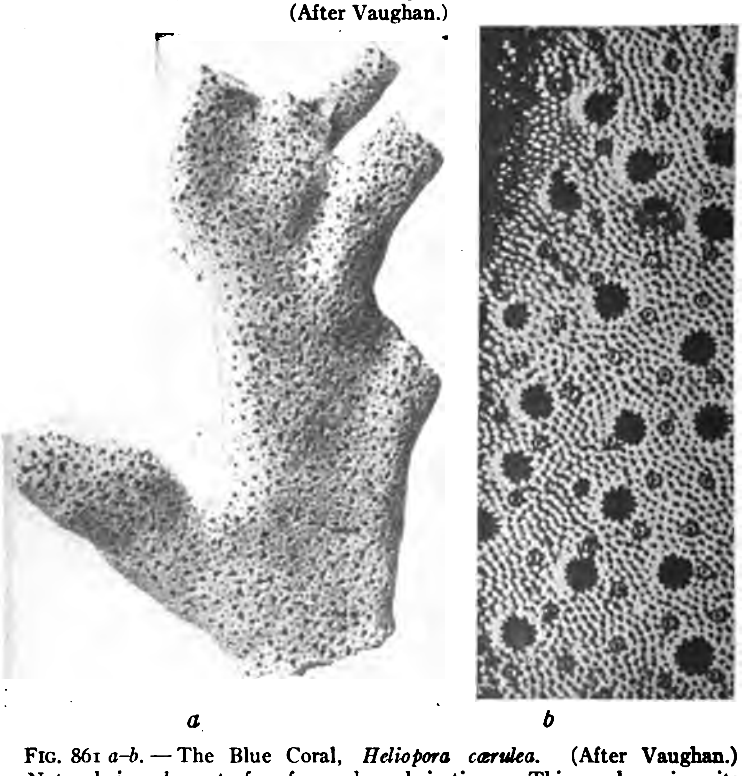


FIG. 859. — *Pocillopora elegans.* A characteristic coral of the modern coral reefs, Fiji Islands. (After Vaughan.)

FIG. 860. — *Anisopsammia ampheleoides*, part of coral stock; natural size. (After Vaughan.)



a b

FIG. 861 *a–b*. — The Blue Coral, *Heliopora cærulea*. (After Vaughan.) *a*, Natural size; *b*, part of surface enlarged six times. This coral receives its name from the cærulean blue of the polyps. It is a characteristic reef-builder, some reefs in the Australian Barrier reef complex being largely composed of it. (See Part I, p. 300.)

begins primarily with the septa, which are arranged on the plan of six (*Hexaseptata*). Along the outer margin these are bound together by transverse plates between the septa in such a way as to form a continuous wall (*theca*), outside of which the ends of the septa often project as *costæ* (Fig. 854). These are mostly compound from budding or division of the older ones. They form branching masses or solid heads, and the individual polyps range from minute size to many inches in diameter, the larger ones often

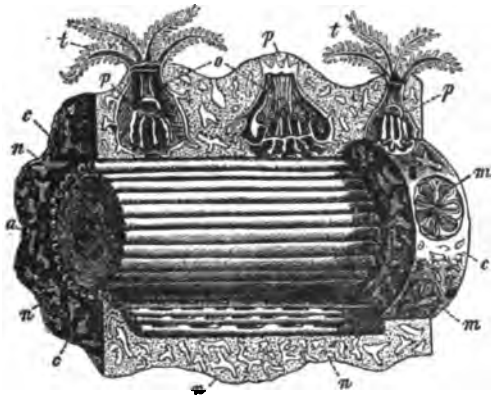
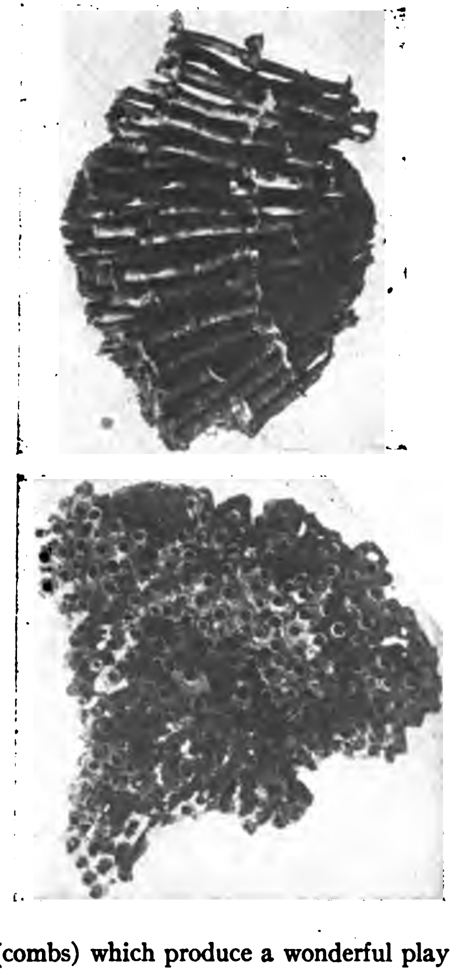


FIG. 862. — Portion of a stock of precious coral (*Corallium rubrum*), enlarged; Mediterranean Sea. *a*, The solid calcareous axis is of red color, and formed of consolidated spicules. The fluted surface is caused by the development of longitudinal tubes; surrounding this is the fleshy *cœnosarc* (*c*), traversed by a network of canals (*n*); the polyps (*pm*) are embedded in the *cœnosarc*; *p*, longitudinal, *m*, transverse section of polyps, showing eight mesenteries; *o*, stomodæum; *t*, fringed tentacles (eight in number). (From Steinmann.)

being single (*Fungia*, Figs. 855 *a*, *b*). These are the corals most common on modern reefs, and they were the common forms in Mesozoic time. (Figs. 856–861. See also Figs. 209–214, pp. 284–287, Pt. I.)

A fourth group has the polyp divided by eight mesenteries (*Octoseptata*), and these generally grow in solid masses or colonies, with the colony rather than the individual building a supporting structure. This is often a horny or calcareous rod around which the mass grows. The sea-fan and sea-whips (*Gorgonia*) are examples of the first, the precious coral (*Corallium*, Fig. 862) of the second. In these the hard parts show no septa, but are commonly fluted or ridged longitudinally. These corals also are most characteristic of the modern oceans. Another type is shown in the organ-pipe coral (*Tubipora*, Figs. 863 *a*, *b*, 864).

Ctenophora. — These are delicate, film-like, more or less transparent globes, bells, or bodies of other form, set with rows of vibrating



a *b*

Fig. 863 *a*, *b*. — The organ pipe coral, *Tubipora musica*. (After Vaughan.) *a*, Top view, showing the surface of one of the connecting floors and the apertures of the tubes; *b*, side view showing the distinct tubes and the edges of the connecting floors (see Fig. 864). The corallum has a deep red color, and it forms extensive reefs in the Great Barrier Reef complex. (See Part I, p. 300.)

cilia (combs) which produce a wonderful play of color. They are common in the modern ocean, but have no hard parts and usually leave no trace after death (Fig. 865).

Bryozoa. — This class of the phylum Molluscoidea comprises polyp-like animals in which the stomach and primitive intestinal tube lie within a cavity inclosed by an outer wall (Fig. 866). It is a more highly specialized type than the coral polyp and has both mouth and anal opening. The animals are always associated in colonies. They live mostly in the sea, though a few fresh-water forms are known. Some build only horny coverings for their bodies,

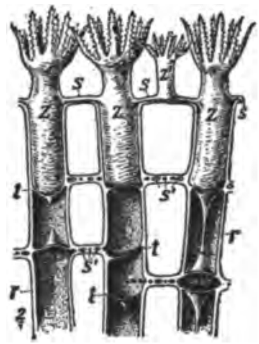


FIG. 864. — Diagram of a portion of the Organ Pipe coral, × 2, showing the position of the polyps (*z*), in the calcareous tubes (*r*); *t*, transverse partitions or *tabulæ*; *s*, connecting stolons; *s'*, tubes in the transverse connecting floors occupied by the stolons; *z'*, new polyp bud arising from the stolons. (After Steinmann.)

others secrete calcareous material. This may be attached to seaweeds, rocks, or shells, etc., or may grow as free fan-like expansions (Fig. 867) or in independent masses made up of crowded calcareous tubes, as in the Monticuliporidæ (Fig. 1131), or form a succession of

FIG. 865. — *Pleurobrachia rhododactyla.* A common Ctenophore of the North Atlantic.

small coffin-shaped, tubular, pear-shaped, or otherwise-formed calcareous cells (*zoœcia*) (Fig. 868). The first two groups were most characteristic of the Palæozoic, the third of Mesozoic and more recent times.

Brachiopoda. — This vastly different class of the Molluscoidea comprises complex organisms in which the main body — with

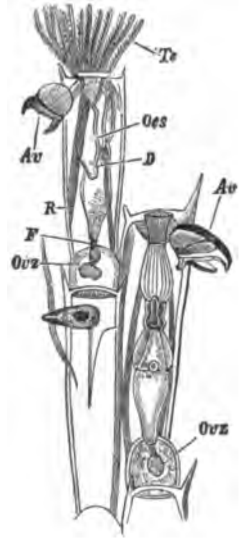


Fig. 866. — Part of a modern bryozoan colony with one expanded animal (zoon) *Bugula*. *Te*, tentacles; *R*, retractor muscle which the animal uses to withdraw into the cell; *D*, intestine; *F*, funiculus, uniting the intestine to the body wall; *Av*, avicularia; *Oes*, œsophagus; *Ovz*, ovicells.

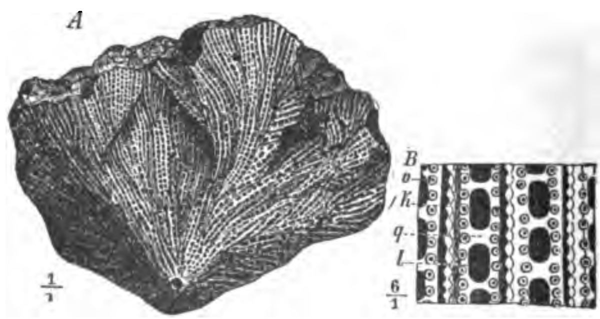


Fig. 867. — *Fenestella retiformis*, Permian (Zechstein), Yorkshire, England. *A*, exterior of complete colony, natural size; *B*, part of interior enlarged (*k*, tubercled keel; *l*, fenestra; *q*, cross bars without zoœcia, *o*, cell mouths). × 6. (Steinmann.)

mouth, stomach, and other organs — is reinforced by two spirally coiled, fringed organs, called the arms or *brachia* (hence the name, arm-footed), which serve both for respiratory and food-gathering purposes (Fig. 869). The whole is inclosed by a fleshy envelope or mantle, which secretes a calcareous or more rarely

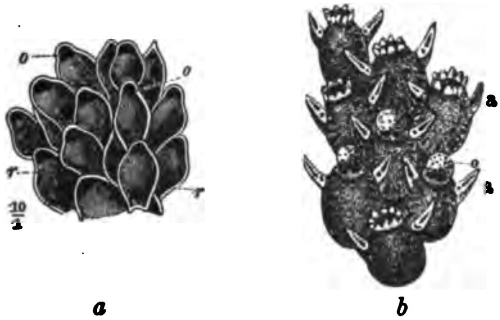


FIG. 868. — Tertiary Bryozoa. *a*, *Membranipora bipunctata* Schafh. Upper Oligocene, near Osnabrück; *r*, calcified cell walls; *o*, apertures, × 10. (Steinmann.) *b*, *Lepralia coccinea* Johnst. Miocene, Hungary; *a*, avicularia; *o*, oœcium; enlarged. (Zittel.)

horny or phosphatic shell. This shell (Fig. 870) consists of two main parts or valves (in some cases with a small third one, called the pedicle plate, Fig. 874 *B* — δ), which are, respectively, the

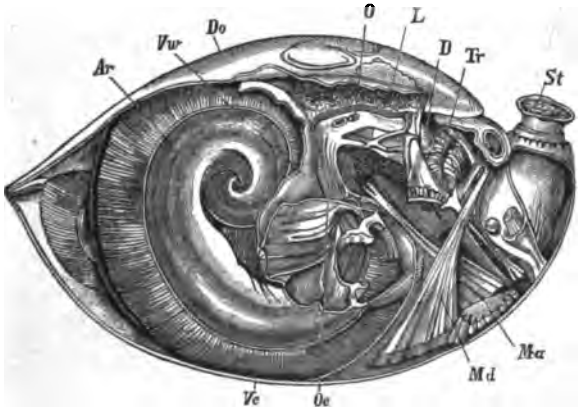


FIG. 869. — Anatomy of a typical modern brachiopod *Waldheimia australis*. Side view. *Do*, dorsal (brachial) valve, and *Ve* ventral (pedicle) valve of shell. *St*, pedicle; *Ma*, adductor muscle (to close shell); *Md*, divaricator muscle (to open shell); *Ar*, arms or brachia; *Vw*, body wall; *Oe*, œsophagus; *D*, blind intestine; *O*, apertural openings for liver (*L*); *Tr*, funnel.

dorsal or brachial (Fig. 870 *B*), and the ventral or pedicle valve (Fig. 870 *A*). The former is so named because it generally bears on its inside small or large, simple or complex (loop-like, spiral, etc.), calcareous supports for the brachia (Fig. 870, *B*—*s*, Fig. 871), while the pedicle valve is perforated at its apex for the protrusion of a fleshy supporting stem or pedicle, minute in some forms, gigantic

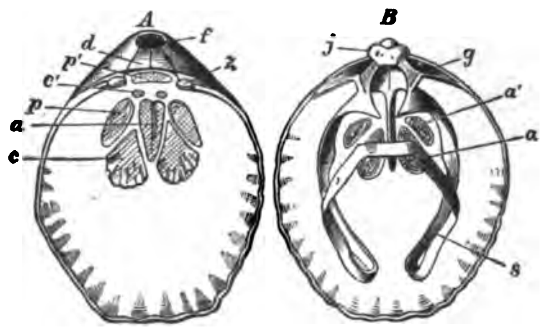


FIG. 870. — Shell of a modern brachiopod, internal views (*Waldheimia flavescens*). *A*, ventral or pedicle valve (*f*, pedicle foramen; *d*, deltidial plates; *z*, cardinal or hinge teeth; *p'*-*c*, muscle scars; *p'*, posterior adjuster; *c'*, posterior divaricators; *p*, anterior adjusters; *a*, adductor muscle; *c*, anterior divaricators). *B*, dorsal or brachial valve; (*j*, cardinal process; *g*, hinge sockets; *a*, anterior adductor; *a'*, posterior adductor; *s*, brachidium or calcareous supporting loop of arms.)

in others (*Lingula*, Fig. 872.) Both valves are symmetrical with reference to a line drawn through their apices, and this generally serves to identify the brachiopod shell. The pedicle valve is usu-

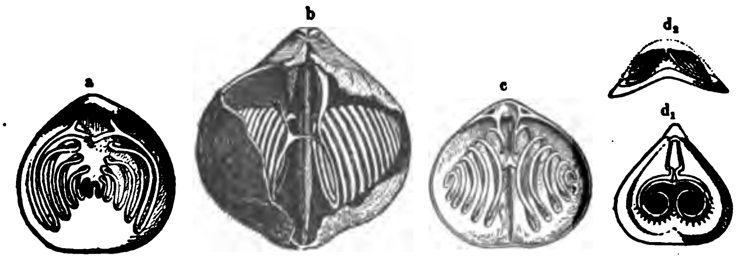


FIG. 871. — Spiral arm supports or brachidia of brachiopods. *a*, atrypoid (*Glassia obovata*); *b*, spiriferoid (*Spiriferina rostrata*); *c*, athyrid (*Nucleospira pisum*); *d*, koninckinid (*Amphiclina*; d_1, against dorsal valve; d_2, frontal view with outline of ventral valve dotted in). (After Zittel.)

ally the larger and more convex of the two, but sometimes the reverse is true (*Atrypa*, Fig. 873). Again one valve may be convex and the other concave (Fig. 874). Plications, radiating lines, and occasionally spines mark the surface, which in some forms, however, is nearly smooth, except for delicate lines which mark the successive additions to the shell and which are always symmetrical with reference to the apex. The valves are held together by teeth and sockets at the apex, and are opened and closed by muscles, which often leave heavy scars at the point of attachment. Brachiopods are typically marine, but some may persist if the water becomes brackish.

FIG. 872.—A modern *Lingula* (*L. murphiana*), showing the shell and long fleshy pedicle.

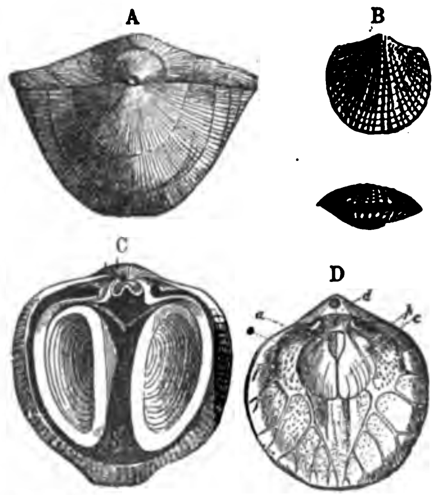


FIG. 873.—*Atrypa reticularis*. *A*, cardinal view of entire specimen; *B*, young; *C*, interior, with pedicle valve removed, showing spirals; *D*, interior of pedicle valve, showing impressions of mantle sinus: *a*, adductors, *c*, divaricators; *d*, deltidial plates; *o*, ovarium; *p*, pedicle muscle. (After Zittel.)

Pelecypoda or Lamellibranchiata. — These are typically represented by the clam. The body (Fig. 875) is soft, with two openings, mouth and anus, but no head. It contains a stomach, intestinal canal, liver, heart, and nerve ganglia, and is covered on either side by delicate leaf-like gills (hence the name, lamellibranch). Its anterior lower portion projects in a hatchet-shaped "foot," used

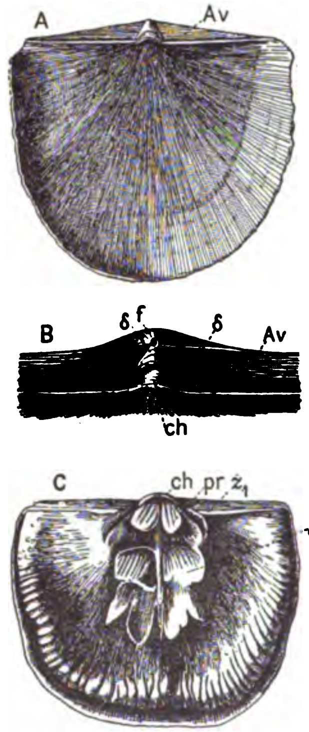


FIG. 874. — *Rafinesquina alternata.* Upper Ordovician, Cincinnati. *A*, from brachial side; *B*, hinge; *C*, interior of brachial valve. (*Av*, hinge area: *a*, adductor impressions; *ch*, chilidium; *δ*, delthyrium; *f*, foramen; *pr*, cardinal processes; *z*, sockets.)

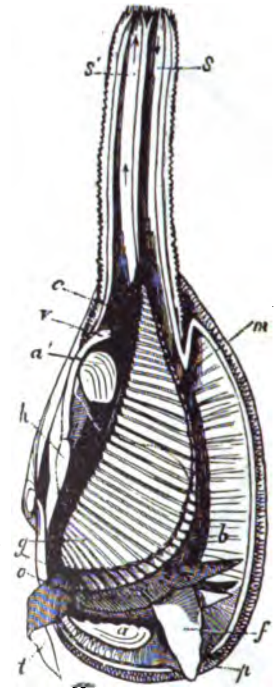


FIG. 875. — Anatomy of the common clam (*Mya arenaria*). (From Woodward.) Left valve and mantle lobe and half of the siphon are removed. (*a*, *a'*, adductor muscles; *b*, body; *c*, cloaca; *f*, foot; *g*, branchiæ or gills; *h*, heart; *m*, cut edge of mantle; *o*, mouth; *ss'*, siphons; *t*, labial tentacles; *v*, vent. Arrows indicate direction of currents.)

for burrowing, or, in some cases, locomotion (Figs. 876, 877). The whole is covered by a delicate membrane or mantle which secretes the shell. The latter consists of two similar parts or valves, each, as a rule, longer behind the beak or apex than in front, though the reverse may be true, or the beak may be near the center (Figs. 878,

FIG. 876. — *Mya truncata* with foot and siphons expanded. One half natural size. (After Forbes.)

FIG. 877. — A pelecypod with foot and siphons expanded. (*Psammobia florida*) right side; *e*, expanded foot; *g*, incurrent siphon; *g′*, excurrent siphon. (From Owen.)

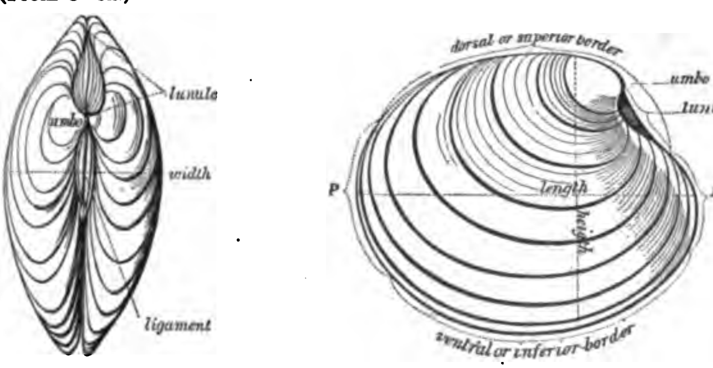


FIG. 878 *a*, *b*. — Shell of pelecypod (*Cytherea*), showing the different parts; *a*, dorsal view, and *b*, side of right valve. (*A*, anterior; *P*, posterior ends.) (After Owen.)

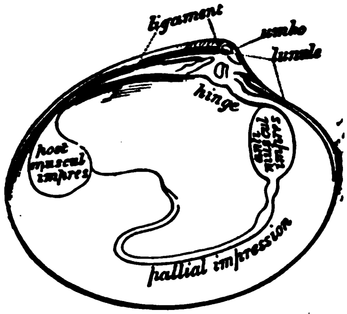


FIG. 879. — Left valve of same shell showing interior characters. (After Owen.)

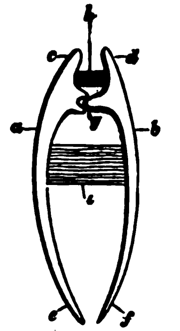


FIG. 880. — Diagrammatic section of a pelecypod shell. *a*, *b*, right and left valves; *c*, *d*, umbones of same, forming the short arms of the lever of which *e*, *f*, constitute the long arms; *g*, hinge; *h*, ligament; *i*, adductor or closing muscle.

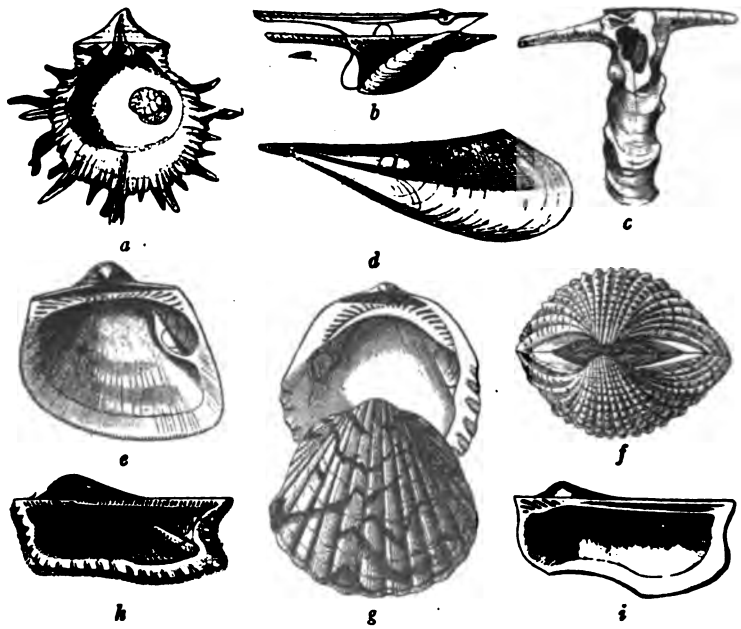


FIG. 881 *a–i*. — Types of Pelecypods chiefly modern. (After Woodward.) *a*, **Spondylus** (*S. princeps*, $\times \frac{1}{2}$, Sooloo Sea); *b*, **Avicula** (*A. hirundo*, $\times \frac{1}{3}$, Mediterranean); *c*, **Malleus** (*M. vulgaris*, $\times \frac{1}{4}$, China); *d*, **Pinna** (*P. squamosa*, $\times \frac{1}{10}$, Mediterranean); *e*, **Cucullæa** (*C. concamerata*, $\times \frac{1}{3}$, India); *f*, **Arca** (*A. granosa*, $\times \frac{2}{3}$, Australia); *g*, **Pectunculus** (*P. pectiniformis*, $\times \frac{2}{3}$, India); *h*, **Arca** (*A. noæ* $\times \frac{2}{3}$, Mediterranean); *i*, **Macrodon** (*M. hirsonensis*, $\times \frac{1}{2}$, Bath Oölite, England.)

a, b, 879). Near the beak the shell generally develops projections or "teeth," those of one valve fitting into grooves or notches (sockets) in the other. There is also a flexible, horny structure which binds the valves together at the top and tends to keep them open when the animal is relaxed (Fig. 880). A compressible substance (resilium) is also found in some forms, just below the

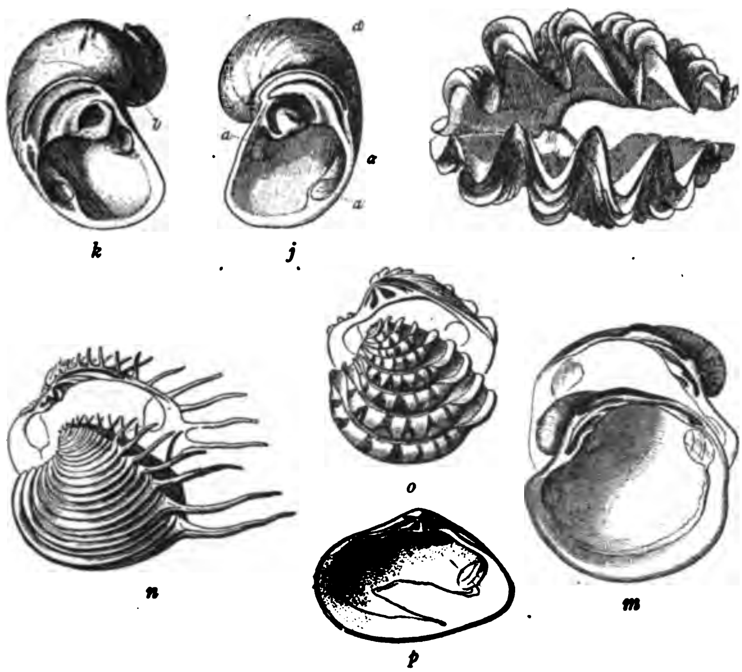


FIG. 881 *j–p*. — Types of Pelecypods, chiefly modern. (After Woodward.) *j, k*, **Diceras** (*D. arietinum*, Coral Oölite, France, opposite valves, × ½); *l*, **Tridacna** (*T. squamosa*, × ⅛, Bombay); *m*, **Isocardia** (*I. cor*, × ½, Britain); *n*, **Cytherea** (*C. dione*, × ⅔, W. Indies); *o*, **Venus** (*V. paphia*, W. Indies); *p*, **Grateloupia** (*G. irregularis*, × ⅔, Miocene, Bordeaux). (See also figs. 234–237, p. 310, Pt. I, and fig. 251, p. 315, Pt. I.)

hinge, and this is compressed when the valves are closed, but tends to spring them open when the closing force relaxes. The closing is done by two muscles, anterior and posterior, though in some forms (oyster, scallops) one of these muscles disappears and the other enlarges. The shell may be smooth, except for lines of growth, or marked by concentric wrinkles (Figs. 878 *a, b*, 881 *o*) or by radiating ridges or both (Fig. 881, *f, g, l*). In some cases spines are also developed (Fig. 881 *a, n*). Most pelecypods live in the sea, but a few (*Unio*, etc.) occur in fresh water.

Gastropoda. — These mollusks have the anterior part of the body developed into a head, with mouth, and eyes (generally on

Fig. 882. — *Haliotis tuberculata* expanded animal with shell. *d*, foot; *i*, tentacular processes of the mantle. (After Owen from Cuvier.)

stalks, feelers, etc., Fig. 882). The foot is broad and flat, and used for crawling upon the stomach, as it were; hence the name (Fig. 883). The mouth is furnished with a heavy ribbon covered with

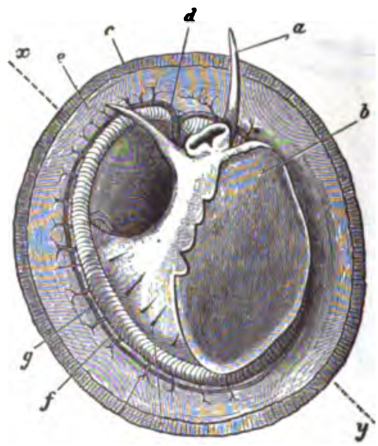


Fig. 883. — Common limpet (*Patella vulgata*) in its shell, seen from the foot surface. *xy*, median antero-posterior axis; *a*, cephalic tentacle; *b*, creeping surface of foot; *c*, free edge of shell; *d*, vessel carrying aërated blood to the heart and here interrupting the circlet of gill lamellæ; *e*, margin of mantle-skirt; *f*, gill lamellæ; *g*, vessel carrying blood to the heart.

teeth (Fig. 884), the so-called ***lingual ribbon***, which is used like a file in cutting off food, or like a drill in boring through the shells of other mollusks. The body grows commonly in a spiral manner, and the shell corresponds to this (Fig. 885). In some cases, how-

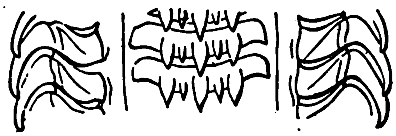


Fig. 884. — Portions of the lingual ribbon of a gastropod (*Murex tenuispina*) much enlarged to show the characteristic teeth. (Wilton, from Woodward.)

ever, it is cap-shaped. The shell is hollow throughout, except perhaps near the apex, where a few transverse partitions may be formed (Fig. 886). The successive coils of the shell are called whorls, and the lower, larger end is the mouth of the shell, permitting the animal to expand from or contract within it (Fig. 887).

Fig. 885. — Animal and shell of *Rostellaria rectirostris*. ***a***, snout or rostrum; ***b***, cephalic tentacle; *c*, eye; ***d***, *e*, foot; *f*, operculum, which closes aperture of shell after soft parts are drawn in; ***h***, prolonged siphonal notch of shell occupied by siphon or trough-like process of the mantle-skirt. (After Owen.)

The shell mouth may be round and complete (Fig. 888 ***m***, *o*, *q*), or drawn out into a canal at one end (Fig. 888 ***a***, ***b***, ***e***), notched (Fig. 888 *f*, *g*, *j*, *l*), slit at the margin (Fig. 888 *t*), or fluted, the flutings prolonged into shallow spines (Fig. 888 *a–c*). Spiral lines (Fig. 888 ***n***, ***o***), transverse wrinkles or ribs (Fig. 888 *g*), and nodes or spines (Fig. 888 ***d***, ***e***, ***i***, ***l***) form the common surface features of these shells, though many are smooth except for lines of growth often obscured by the color pattern (Fig. 888 *f*, *i*, *h*, *j*). Most gastropods are

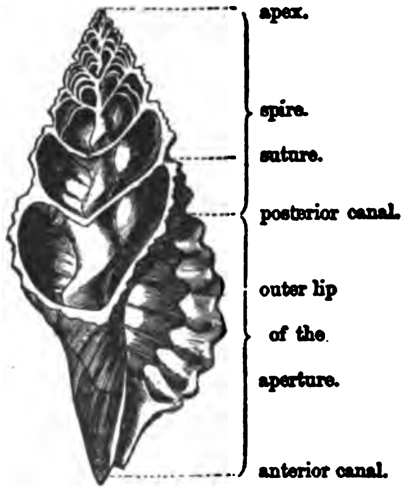


FIG. 886. — Longitudinal section of a gastropod shell (*Triton corrugatus*) showing the parts. (After Woodward.)

FIG. 887. — Animal and shell of *Pyrula lævigata*. *a*, siphon; *b*, head-tentacles; *C*, head with eyes; *d*, expanded foot; *h*, mantle-skirt reflected over the sides of the shell. (After Owen.)

marine. A few with unnotched shell-mouth occur in fresh water, and a number live on land. The latter have a primitive lung-

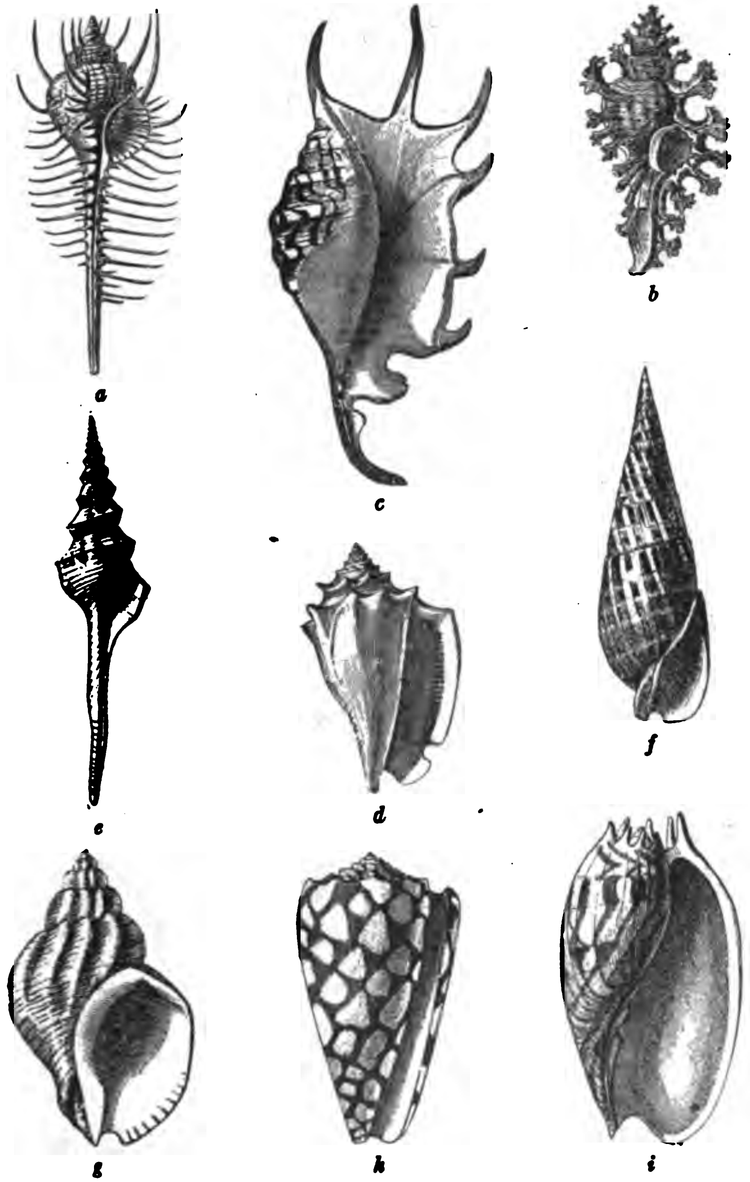


FIG. 888 *a–i*. — Types of modern Gastropods. (After Woodward.) (For description see page 125.)

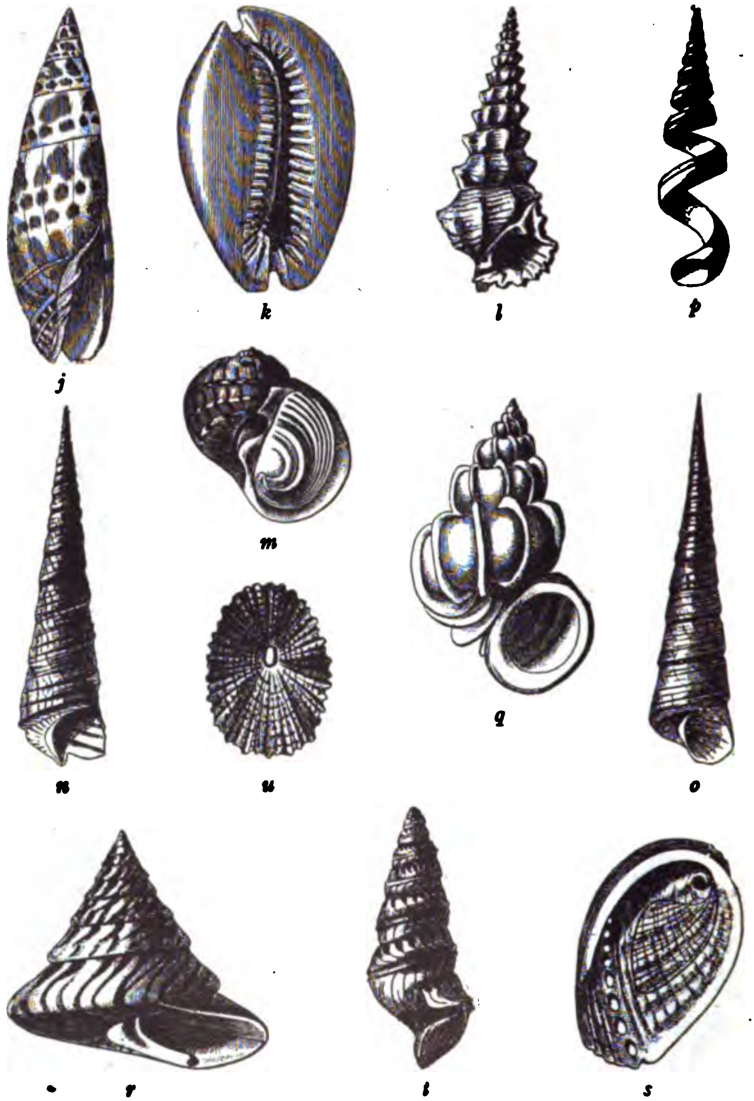


FIG. 888 *j–u*. — Types of modern Gastropods. (After Woodward.) (For description see page 125.)

sac, and their shells are generally thin (*Helix*, Fig. 889 *a*). Most gastropod shells coil clockwise (right-handed) when viewed from the apex. A few coil in the reverse manner (left-handed) (*Physa*, Fig. 773 *b*, p. 52).

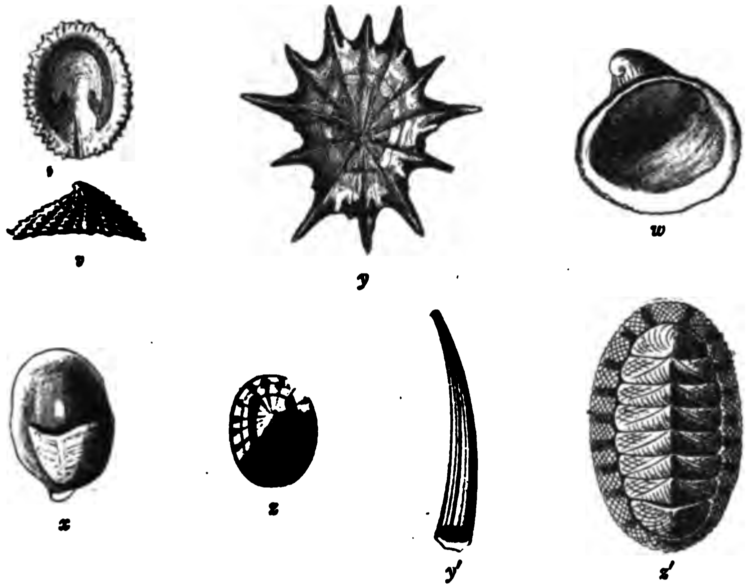


FIG. 888 *v–z*.—Types of modern Gastropods. *y′*, Scaphopod and *z′*, Amphineuran. (After Woodward.) (For description see below.)

FIG. 888.—Types of Gastropods, chiefly modern (pp. 123–125). *a*, **Murex** (*M. tenuispina* ($\times\frac{2}{5}$) Moluccas); *b*, **Murex** (*M. palma-rosæ* ($\times\frac{1}{3}$)); *c*, **Pteroceras** (*P. lambis* ($\times\frac{2}{5}$) China); *d*, **Strombus** (*S. pugilis* ($\times\frac{1}{3}$) West Indies); *e*, **Fusus** (*F. colus* ($\times\frac{1}{3}$) Ceylon); *f*, **Terebra** (*T. maculata* ($\times\frac{1}{2}$) Moluccas); *g*, **Buccinum** (*B. undatum* ($\times\frac{1}{2}$) North Atlantic); *h*, **Conus** (*C. marmoreus* ($\times\frac{2}{3}$) China); *i*, **Melo** (*M. diadema* ($\times\frac{1}{3}$) New Guinea); *j*, **Mitra** (*M. episcopalis* ($\times\frac{1}{2}$) Ceylon); *k*, **Cypræa** (*C. mauritiana* ($\times\frac{1}{2}$) Indo-Pacific); *l*, **Cerithium** (*C. nodulosum* ($\times\frac{1}{3}$) Moluccas); *m*, **Natica** (*N. canrena* ($\times\frac{1}{2}$) China); *n*, **Turritella** (*T. cathedralis* ($\times\frac{1}{2}$) Miocene, Bordeaux); *o*, **Turritella** (*T. imbricata*, West Indies); *p*, **Vermetus** (*V. lumbricalis*, young, West Africa); *q*, **Scalaria** (*S. pretiosa* ($\times\frac{2}{3}$) China); *r*, **Trochus** (*T. niloticus* ($\times\frac{1}{4}$) China); *s*, **Haliotis** (*H. tuberculata*, Guernsey); *t*, **Murchisonia** (*M. bilineata*, Devonian, Eifel); *u*, **Fissurella** (*F. listeri*, West Indies); *v*, **Emarginula** (*E. rugosa*, two views, Tasmania); *w*, **Pileopsis** (*P. varicus* ($\times\frac{2}{3}$) Torbay); *x*, **Crepidula** (*C. fornicata* ($\times\frac{2}{3}$) Atlantic coast); *y*, **Patella** (*P. longicosta* ($\times\frac{2}{3}$) Cape); *z*, **Acmæa** (*A. testudinalis* ($\times\frac{2}{3}$) Britain); *y′*, **Dentalium** (*D. elephantinum* ($\times\frac{1}{2}$) Red Sea); *z′*, **Chiton** (*C. squamosus* ($\times\frac{1}{2}$) West Indies). (All from Woodward.) (See also Figs. 238–241, pages 311, 312, Pt. I, and Figs. 252–256, pages 315, 316, Pt. I.)

Pteropoda and Conularida. — Pteropods are marine planktonic mollusks shell-less or with delicate, often transparent shells, conical or variously formed, and generally small. The upper part of

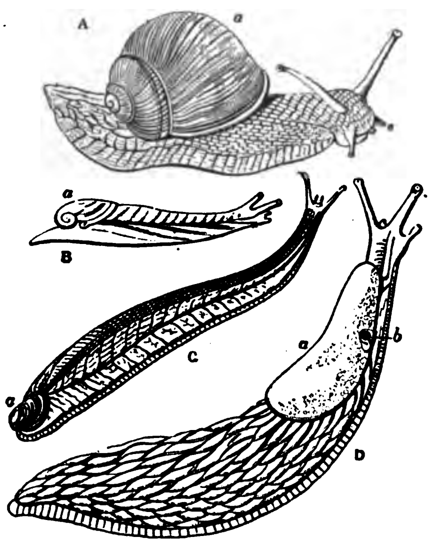


FIG. 889. — Snails and slugs (Pulmonate gastropods). *A*, *Helix* (snail); *B*, *Helicophanta*; *c*, *Testacella*; *d*, *Arion* the great black slug. (*a*, in *A*, *B*, *C*, shell-sac; closed in *D*; *b*, opening leading into lung chamber. *B*, *C* are transitional forms between snail and slug, showing gradual reduction of shell.) (After Lankester.)

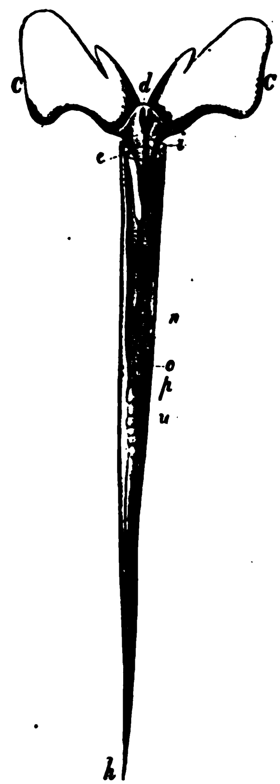


FIG. 890.—*Styliola acicula.* Enlarged. (After Owen.) *CC*, wing-like lobes of the mid-foot; *d*, median fold of same; *e*, copulatory organ; *h*, pointed extremity of shell; *i*, anterior margin of shell; *n*, stomach; *o*, liver; *u*, hermaphrodite gonad.

the body (foot) is divided into two wing-like lobes, hence the name, wing-footed; (Figs. 890, 891). Their importance as rock-formers has already been noted (p. 311, Pt. I). The Conularida are extinct forms with heavier shells of various form, and some of them, at least, appear to have lived upon the bottom of the sea (Fig. 892). No fresh-water types are known.

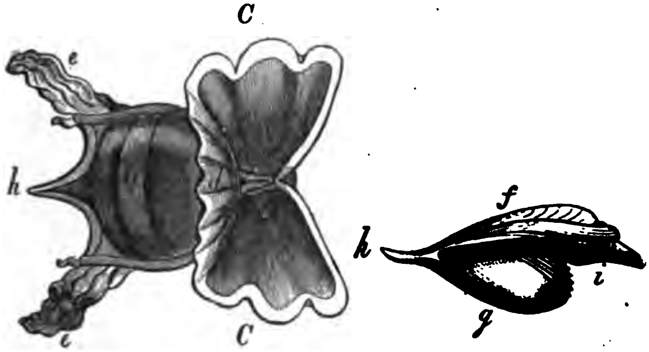


FIG. 891. — *Cavolinia tridentata*, top and side views. From the Mediterranean; magnified two diameters. (From Owen.) *a*, mouth; *b*, pair of cephalic tentacles; *CC*, pteropodial lobes of the mid-foot; *d*, median web connecting these; *ee*, processes of the mantle-skirt reflected on the surface of the shell; *g*, the shell enclosing the visceral hump; *h*, the median spine of the shell; *i*, mouth of the shell.

Cephalopoda. — These are the most highly developed of Mollusca. They are represented in the modern sea by the pearly *Nautilus* (Fig. 893), the squids, and cuttlefish (Fig. 894), devil fish or

FIG. 892. — *Conularia undulata* ($\times \frac{5}{8}$), a Palæozoic conularid (Devonian).

Octopus (Fig. 895), the *Argonauta* (Fig. 896), *Spirula* (Fig. 897), and a few others. The modern *Nautilus* alone builds an external shell, but in former times these shell-building types (Tetrabranchiata) abounded. The animal has a definite head, with a mouth

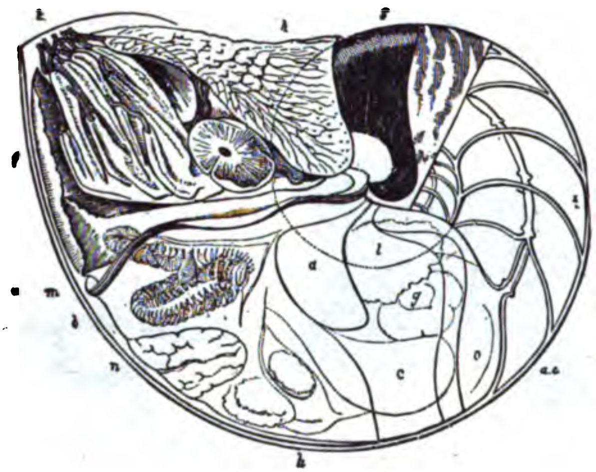


FIG. 893. — *Nautilus pompilius* in its shell. *a*, shell muscle; *a.c*, air-chambers and siphuncle; *b*, branchiæ; *c*, crop; *f*, funnel; *g*, gizzard; *h*, heart and renal glands (in dotted lines); *l*, liver; *m*, margin of mantle, very much contracted; *n*, nidamental gland; *o*, ovary; *s*, portion of shell; *t*, tentacles; *h*, at top of figure, hood extending back over shell (*s*). (From Woodward.)

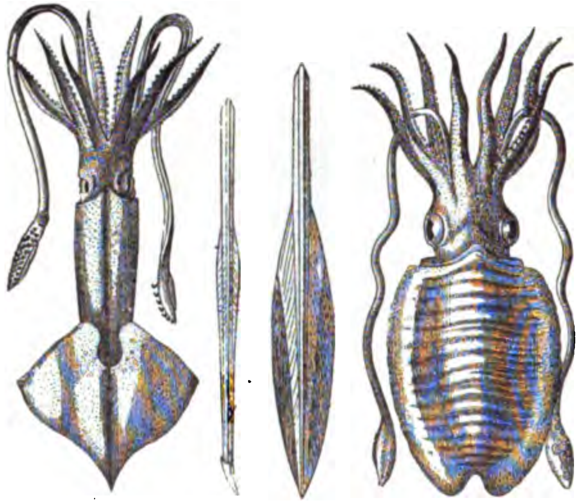


FIG. 894 *a–d*. — Modern squids and cuttle-fish. (After Woodward.) *a*, *Onychoteuthis bartlingii*, squid from Indian Ocean, one fifth natural size; *b*, horny internal shell or pen (*gladius*) of same species, one fourth natural size; *c*, *gladius* of *Loligo vulgaris* (Fig. 247, p. 314, Pt. I) one fifth natural size; *d*, *Sepia officinalis*, cuttle-fish from Atlantic Ocean, one seventh natural size. (See Fig. 248, p. 314, Pt. I, for shell remnant.)

FIG. 895. — The common *Octopus* or devil-fish. (After Brehm.)

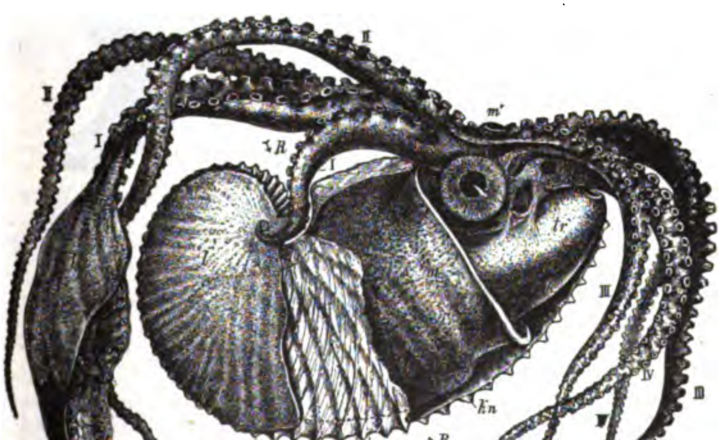


FIG. 896. — The modern *Argonauta* (*A. argo*), living in the Mediterranean. Female with the shell partly broken. *R*, dorsal side; *B*, ventral side; *m*, mantle; *tr*, squirt tube (hyponomic funnel); *m'*, mouth; I–IV, four pairs of arms; I, dorsal pair of arms, lying in a spiral excavation of the shell and enclosing the shell with its broad terminal lobes (*l*); *r*, costæ or ribs of the shell; *zw*, growth lines of shell; *kn*, ventral nodes of shell. (After Steinmann.)

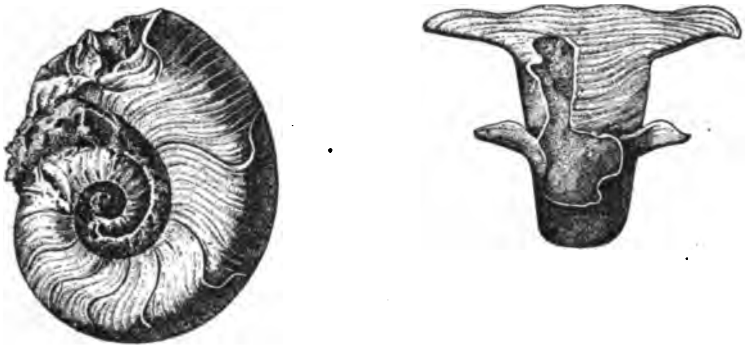
furnished with strong, horny beaks, and large but primitive eyes. The head is surrounded by a ring of arms (used also as feet, hence the name, head-footed). The arms are often furnished with powerful suckers, as in the *Octopus*, squid, and cuttlefish. The shell is always divided by transverse partitions into numerous air-chambers, and a terminal body-chamber, which alone harbors the animal.

FIG. 897. — *Spirula lævis*, showing the soft-bodied animal with included spiral shell; one half natural size. New Zealand. (After Woodward.)

FIG. 898. — *Orthoceras tumidum*. A part of the shell preserved. The remainder shows the solidified mud-filling of the interior divided by the septa, the edges of which form the "sutures." Silurian, Bohemia.

FIG. 899. — *Cyrtoceras murchisoni*, Silurian of Bohemia. A part of the shell is preserved.

Nautiloids. — The simplest forms occur in the Palæozoic, where the open oceans seem to have been peopled primarily by straight shells (*Orthoceras* type, Fig. 898). These are long, slightly tapering tubes, the greater part of which is divided at regular and frequent intervals by saucer-shaped partitions or septa placed with the concavity upward, and each pierced by a central or eccentric hole, which is prolonged downward into a short tube (siphonal funnel). When the shell and its chambers are filled with hardened mud and the shell broken away or dissolved, the edges of these septa appear as regular concentric dividing lines. They are then called sutures.



a *b*

FIG. 900. — *Gyroceras alatum.* *a*, side view; *b*, ventral view; showing former and final apertural expansions. (After Barrande.)

As the orthoceran types successively entered the epeiric seas, their descendants lost the straight mode of growth, one side of the shell growing faster, so that it became curved (*Cyrtoceras* type,

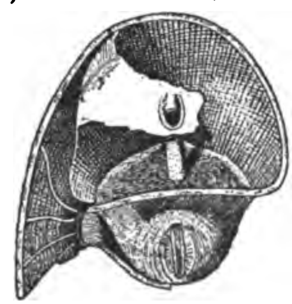


FIG. 901. — Earliest shell stages of the modern *Nautilus* (*N. pompilius*) obtained by breaking down the shell. At the lower end the scar where the perishable protoconch was attached is shown. The first septum, the siphuncle, and the second septum (broken) are shown. Note the flattening of the inside of the section at this early stage.

Fig. 899). Still more rapid asymmetric growth produced a coiled shell, the coiling being usually in a single plane, like that of a watch spring (*Gyroceras* type, Fig. 900). With extreme rapidity of growth on one side, the inner margin of the tube was flattened against the preceding coil, as a partially deflated automobile tire is flattened on the side in contact with the ground. Finally, with still greater pressure, due to increased rapidity of

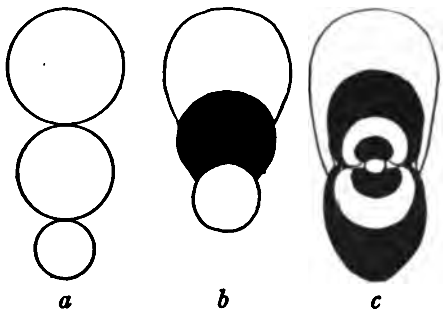


FIG. 902 *a–c*. — Diagrams showing the development of the impressed zone in coiled cephalopod shells. These outlines represent the whorls in vertical section through the shell. *a*, sections of three whorls in contact; *b*, three whorls, showing partial involution with impressed zone; *c*, section of entire shell showing complete involution, and deep impressed zones. Alternate whorls in black. (Original.)

growth, the inner side of the coil became indented by the preceding one, and this indentation went so far in some cases that the projecting edges of the indented coil covered all the preceding ones. This produced the *Nautilus* type (Fig. 901). The stages are shown in section in the above diagrams (Fig. 902 *a–c*).

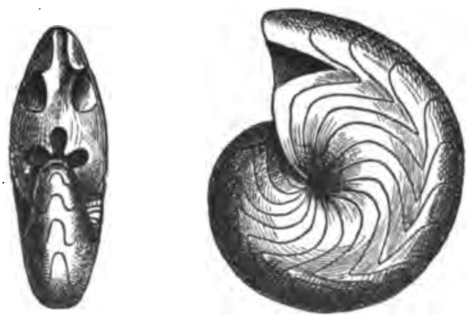


FIG. 903. — A goniatite (*Goniatites* (*Aganides*) *rotatorius*). Lower Mississippian, Rockford, Indiana. Internal mold with shell removed, showing the edges of the septa, *i. e.* the sutures. Note their simple lobes and saddles.

In the older formations the processes did not go much beyond that of flattening, after which the coiled types died out. In later periods, the change went on more rapidly and deeper indentations resulted. Finally, only deeply indented nautiloid forms remained, the others having died out. Thus a regular progress in development with time is witnessed.

Ammonoids. — In the Devonian some nautiloids modified their septa by a simple fluting of the margins, giving to the suture

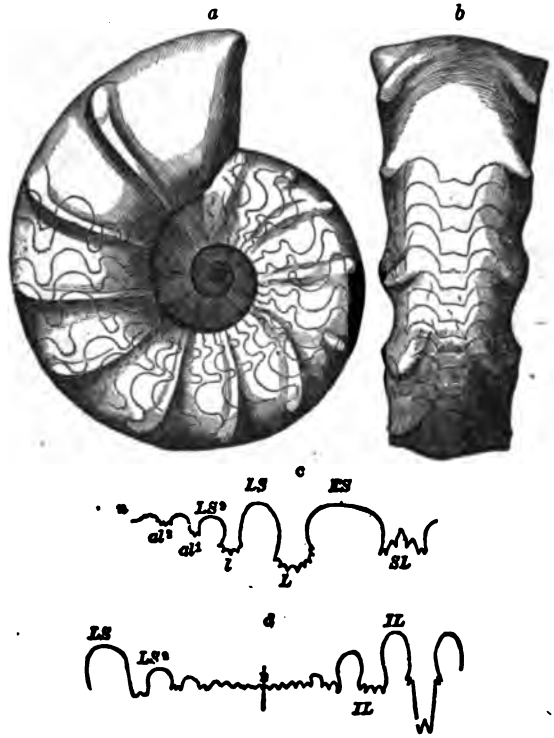
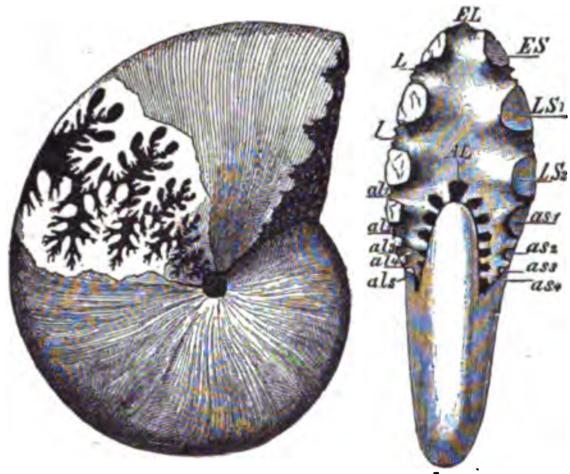


FIG 904. — A typical ceratite (*Ceratites nodosus*). Muschelkalk, Würzburg. *a* and *b*, specimens one half natural size; *c*, suture line on the outside — from venter (*SL*) to umbilicus (*n*); *d*, continuation of suture line from lateral saddle (*LS*) past the umbilical line (*n*) to center of dorsum in covered part of whorl (right); *SL*, *L*, *l*, al^1, al^2; ventral and lateral lobes; *IL*, inner lobes; *ES*, *LS*, LS^2, ventral and lateral saddles. (From Haas, *Leitfossilien*.)

an undulatory outline, which, when pronounced, shows forward-bending saddles and backward-bending lobes. This is the *goniatite* form, which became very characteristic of the later Palæozoic (Fig. 903). When, at the end of the Palæozoic, great physical changes caused widespread extinction of life, these goniatites, having probably adopted a pelagic life, were the chief representatives of the cephalopods. During the Mesozoic, their descendants gave rise to a wonderfully complex and varied series of types. At first, the lobes of the suture were further divided by narrow notches. This produced the *ceratite* type, which was especially characteristic of the Triassic period (Fig. 904). Next the saddles also became divided, and the *ammonite* types developed (Fig. 905). This line of modification, once started, continued with increasing complex-



a *b*

Fig. 905. — A smooth-shelled ammonite (*Phylloceras heterophyllum*) Lias, Whitby, England. *a*, specimen with shell partly removed to show complex suture; *b*, front view showing a septum smooth at center but regularly fluted at the margins. (*EL*, "keel"; *L*, first lateral lobe; *l*, second lateral lobe; al_1 to al_4, accessory lobes; al_s, accessory lobe of umbilicus; *ES*, outer saddle; *LS*, first lateral saddle; LS_2, second lateral saddle; as_1 to as_4, accessory saddles.) (From Haas, *Leitfossilien.*)

ity, and during the Jurassic and early Cretaceous (Comanchean) the ammonites presented a variation, not only in their sutures but in their forms and shell markings as well (Fig. 906). These latter consisted of spiral lines, of transverse wrinkles or ribs, and in later types of rows of nodes and spines at the intersections of the two. The progressive increase in complexity of sutures is shown in Fig. 782, p. 58 (see also, Figs. 907, 908).

In all cases, as previously noted, the young shell is less strongly marked than the adult, and may be altogether smooth. Furthermore, the suture in the young shell is much simpler than in the

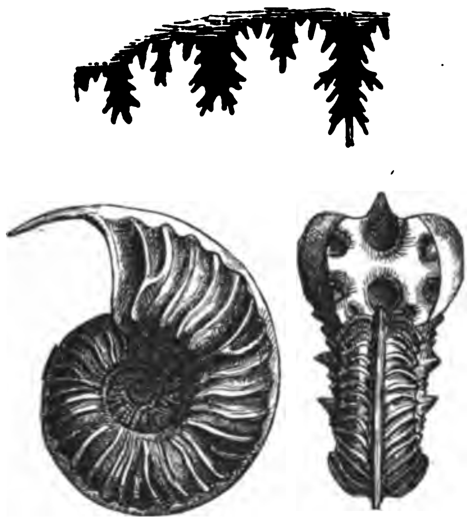


FIG. 906. — A complex ammonite (*Schloenbachia cristata*). Comanchean, (Gault), France. Two views of shell and suture. (After D'Orbigny. Haas, *Leitfossilien.*)

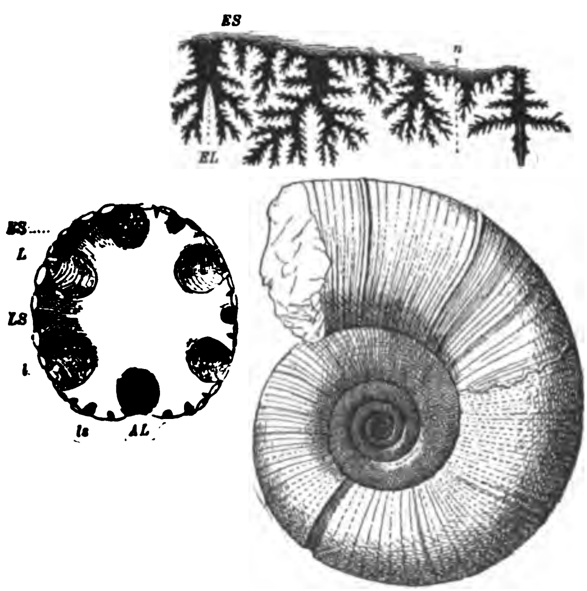


FIG. 907. — An ammonite (*Lytoceras*, Upper Jurassic), showing the smooth center of the septum passing outward into fluted margins. (After Zittel.)

adult. Indeed, in the earlier stages the ammonite has all the characters of a goniatite, and it may be said that all ammonites pass through a goniatite stage in their individual development, just as

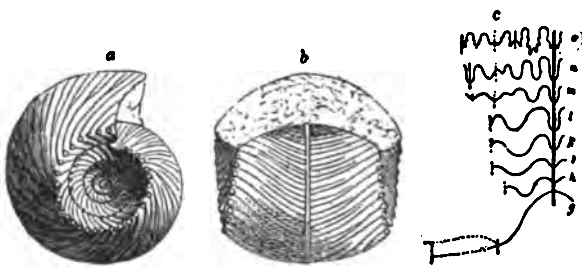


FIG. 908. — Development of the suture in an ammonite (*Tropites subbullatus*). *a*, side view of ammonite; *b*, apertural or oral view; *c*, sutures. (*g–l*, simple sutures on first volution of shell; *m–o*, progressively more complex sutures on second volution of shell.) (After Zittel, *Grundzüge*.)

the races of ammonites were preceded by goniatites which were their progenitors. In other words, the individual ammonite repeats, in a brief manner, in its own development, the life history of its race (Fig. 908).

By the time the Cretaceous period was reached in the history of the earth, many racial lines of ammonites had died out, while others

FIG. 909. — *Scaphites*, an ammonoid type in which the last whorls are loose-coiled, in part straightened. (After Steinmann.)

had developed extremes of surface characters (often called ornamentations). Some of them, like *Scaphites* (Fig. 909), had begun to lose their power of coiling in the adult stage. They always present a curvature on a much larger radius than normal, with usually a final recurving of the last part. One group, the *Baculites*

(Fig. 910), coiled only during the very earliest stages, and later continued to grow as a straight tube. Others again returned to a loose coiling habit (*Crioceras*, etc., Fig. 911). Still another series underwent a continued and variable change in direction as it grew, and thus

FIG. 910.—*Baculites anceps*. Cretaceous. A terminal straight shelled member of an ammonoid series. (After Steinmann.)

FIG. 911. — Types of loose-coiled ammonoids. *A*, *Crioceras duvali* (×$\frac{1}{4}$), Comanchean (Neocomian); *B*, *C*. (*Ancyloceras*) *matheroni* (×$\frac{1}{8}$) Comanchean (Aptian). (After Steinmann.)

produced grotesquely twisted and contorted forms (*Heteroceras*, etc., Figs. 912, 913). All these changes may be regarded as the final manifestation of declining vitality of the race, for by the end of the Mesozoic all the ammonites had died out, not a single member of the group continuing into the Tertiary era, where, however, the less complexly constructed *Nautilus* still existed, this group continuing even to the present time.

Another type of degeneration affected the suture rather than the form, with the result that, in the Upper Cretaceous, there are a number of ammonites which have all the characteristics of that group, except for the suture, which never passes beyond the ceratite stage. Such forms have been called collectively *pseudoceratites* (Fig. 914).

Belemnites. — Toward the close of the Palæozoic, another race branched off from the last survivors of the straight-shelled orthoceran

FIG. 912. — *Heteroceras* (*Nipponites*) *mirabilis* Yabe, Cretaceous, Japan. An extremely convoluted cephalopod shell, illustrating "death spasms" of the race. (After Yabe.)

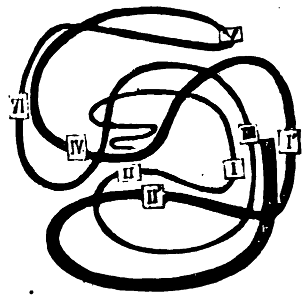


FIG. 913. — *Heteroceras* (*Nipponites*) *mirabilis*. Wire model of the individual illustrated in Fig. 912, showing the mode of coiling. (After Yabe.)

type. In this new group, the Belemnites, apparently the first of the two-gilled or dibranchiate forms, the animal seems to have outgrown the shell and gradually begun to envelop it as some sea-snails envelop their shells by the expanded mantle (Fig. 887 and *Cypræa*, Fig. 888 *k*). In the belemnite group the enveloping mantle

FIG. 914. — Degenerate type of suture of an Upper Cretaceous ammonite (*Engonoceras hilli*), which has remained permanently in the ceratite stage.

deposited additional calcareous material around the shell, producing eventually a solid, cigar-shaped structure of lime, in the upper part of which the shell was embedded (Fig. 915). This structure, known as the *guard*, is a common one in the Jurassic and even the Cretaceous rocks (Fig. 916), but after that time the guard underwent a reduction, and in the modern dibranchiates, some of which still develop an internal shell (*Spirula*, Fig. 897), it has disappeared.

Platyhelminths and Worms. — As these are soft-bodied animals, they seldom leave a record in the rocks, except in the form of castings, or as burrows in the sand, tubes constructed of sand grains,

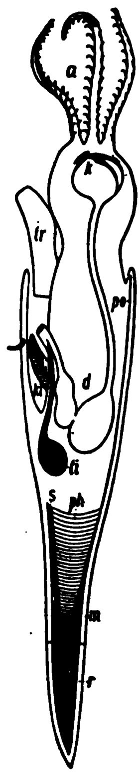


FIG. 915. — Reconstruction of a belemnite in longitudinal section. *a*, arms; *d*, intestinal tract; *k*, jaws; *ki*, gills; *m*, mantle; *ph*, phragmocone or shell proper; *po*, proöstracum; *r*, rostrum; *s*, siphuncle; *ti*, ink bag; *tr*, hyponome. (After von Stromer.)

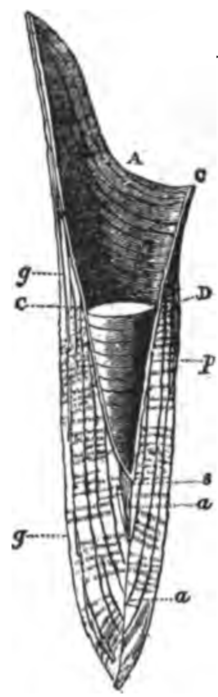


FIG. 916. — Diagram of the structure of a belemnite. *A*, anterior shell process (proöstracum); *CC*, conotheca or thin shell wall of phragmocone; *D*, guard; *aa*, axis of guard; *gg*, growth lines of laminæ of guard; *p*, shell proper or phragmocone; *s*, end of siphuncle. (After Woodward.)

or, in the case of a few types, calcareous tubes (*Spirorbis*, *Serpula*, Fig. 917). In rare cases impressions of the soft parts are also preserved (Fig. 918, see also Figs. 1040, 1041). Some marine worms develop horny, jaw-like structures within the body, and these may be preserved. Even in the Palæozoic deposits there are many such structures, called *conodonts*, which appear to be the œsophageal " jaws " of worms (Fig. 919).

Crustacea. — These arthropods, or creatures with jointed legs, have abounded in all the known periods of the earth's history, having been found even in the oldest fossiliferous rocks. The several sub-classes will be considered separately.

Fig. 917. — Fossil worm tubes. *a*, *Serpula limax.* Middle Jurassic, Franken. *b* and *c*, *Serpula gordialis*, Cenomanian, Saxony; *d*, *S. convoluta*, Middle Jurassic, Württemberg; *e*, *f*, *S.* (*Galeolaria*) *socialis*, Middle Jurassic, Baden (*f* enlarged); *g*, *S. septemsulcata*, Cenomanian, Saxony; *h*, *S.* (*Rotularia*) *spirula*, Eocene, Italy; *i*, *Terebella lapilloides*, Upper Jurassic, Franken. (After Zittel, *Grundzüge*.)

Trilobites. — These are among the oldest marine crustaceans, and they represent a group which was entirely confined to the Palæozoic, becoming extinct at the close of that era (Fig. 920). They derive their name from the fact that the body, which is covered with a hard, lime-impregnated skin or exoskeleton, like that of lobsters and crabs, is divided longitudinally into three parts or lobes, a middle or axial one and a lateral one on each side. Transversely, too, there are three regions: the head, thorax, and pygidium. The head or cephalon is approximately semicircular in outline, with a median, more or less raised and lobed division, the glabella, and lateral cheeks, which in most groups are divided by a line or suture into inner, or fixed, and outer, or free cheeks, the latter carrying the large compound eyes, when these are present. In some

FIG. 918. — Compressed marine worm (*Eunicites avitus*). Lithographic platy limestones, Eichstädt, Bavaria. (After Ehlers.)

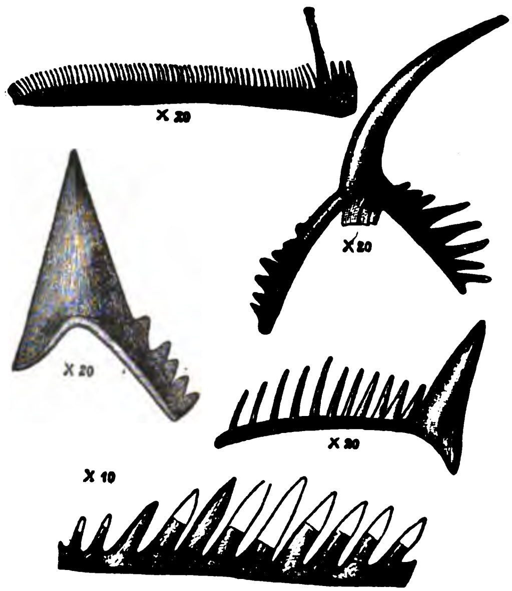


FIG. 919. — Conodonts, supposed to be œsophageal teeth of worms. (After Hinde.)

cases these compound eyes carry an exceedingly large number of lenses, fifteen thousand being the maximum reported in one case for each eye. Usually, however, the number is much smaller (Fig. 921).

On the under side of the cephalic shield special mouth structures, including a plate known as the *hypostoma*, or upper lip, are developed (Fig. 922). Tentacles and other organs have also been detected in well-preserved forms. The thorax, or middle region, consisted of rings (varying in number for different genera), each of which had an axial portion and lateral pleuræ. They were movable, so that the animal was enabled to roll itself into a ball. On the under side of the thoracic segments legs and gill structures were developed, these being visible only in well-preserved speci-

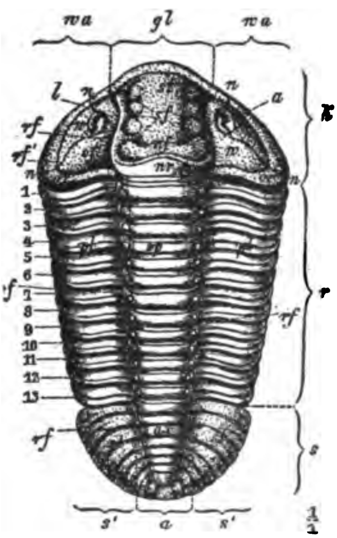


FIG. 920. — Trilobite (*Calymmene tuberculata*), showing parts. *k*, cephalon; *a*, eye; *gl*, glabella; *l*, outer rim; *n*, facial suture; *nf*, neck furrow; *nr*, occipital ring; *of*, posterior furrow; *or*, posterior marginal rim; *rf*, dorsal furrow; *rf'*, marginal furrow; *sf*, lateral furrows of glabella; *st*, frontal lobe; *wa*, cheek; *w*, fixed cheek; *w'*, free cheek; *r*, thorax (1–13 movable thoracic rings); *pl*, pleuræ; *rf*, dorsal furrow; *sp*, rhachis or axis); *s*, pygidium (*a*, *ax*, rachis or axis; *cf*, dorsal furrows; *s'sl*, lateral lobes). Natural size. (After Steinmann.)

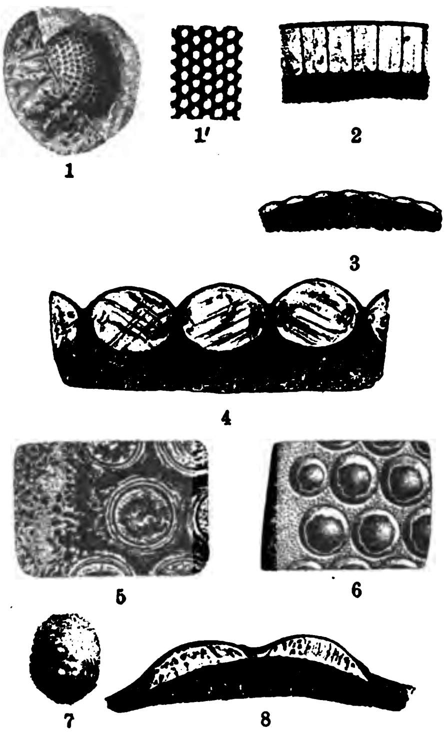


FIG. 921. — Visual surfaces of the eyes of trilobites. 1, *Peltura scarabæoides* × 20; 1', *Asaphus*, part of visual surface ×30; 2, *Asaphus fallax* (vertical section × 60); 3, *Sphærophthalmus alatus* (vertical section × 100); 4, *Phacops macrophthalmus* (vertical section × 30); 5, horizontal section of same × 20; 6, *Dalmanites imbricatula*, lenses partly destroyed × 14; 7, stomata of *Harpes vittatus* × 8; 8, section through stomata of same, showing nearly plano-convex lenses surrounded marginally by integument. (After Lindström.)

mens (Fig. 923). The pygidium, or abdomen, was again a solid piece, but superficially grooved to resemble the thorax. In some forms it was very small, in others equal to the cephalon in size.

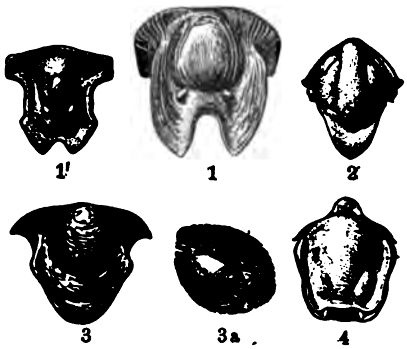


FIG. 922. — Hypostomes of trilobites and *Apus*. 1', *Calymmene intermedia*, X 2½; 1, *Ptychopyge cincta*, X 3; 2, *Encrinurus punctatus*, X 2; 3, *Bronteus polyactin*, X 1½; 3 *a*, right macula of same, X 8; 4, *Apus cancriformis*, X 5. (After Lindström.)

Sometimes it terminated in a spine or telson. (See further illustrations in the chapters dealing with the several Palæozoic systems.)

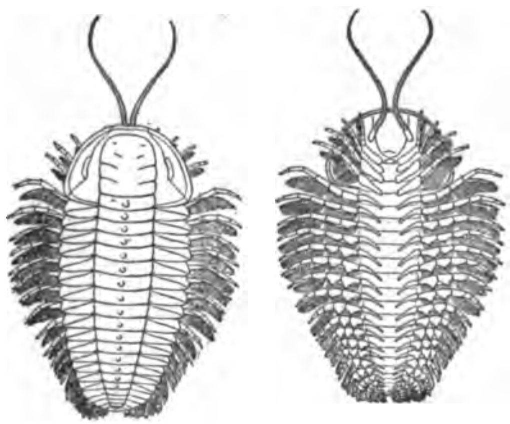


FIG. 923. — *Triarthrus beckii*, top and bottom views, showing the appendages, enlarged. (After Beecher.)

Entomostraca. — A second group, the *Entomostraca*, often living in fresh water (*Estheria*, Fig. 924), had the body mostly inclosed by a horny shell of several pieces, in most types, although the ostracods, which were chiefly marine, were inclosed in a bivalve calcareous shell (Fig. 926 *a*). These were mostly small, the largest not much larger than a bean, which they also resembled in general shape (Fig. 927). A single silicified ostracod has been found in the Upper Carbonic

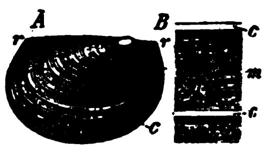


FIG. 924. — *Estheria minuta*, Triassic. *A*, shell, lateral view, × 6 (*rr*, dorsal edge; *c*, growth lines); *B*, portion of shell surface, × 50 (*c*, growth lines; *m*, mesh-structure). (After Steinmann.)

of St. Etienne, France, in which some of the internal organs are preserved (Fig. 926 *b*).

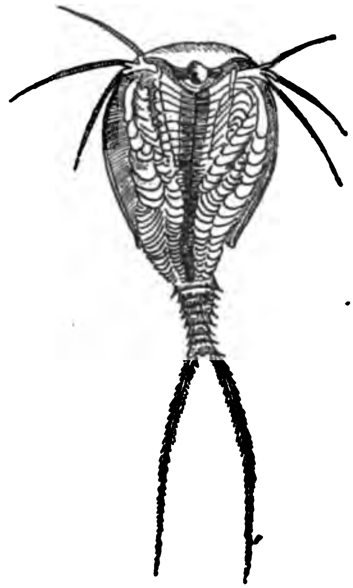


FIG. 925. — *Apus*, a modern phyllopod crustacean, top view. (After Heck, etc., *Das Tierreich.*)

Cirripedia (Barnacles). — A degenerate group of crustaceans is represented by the *barnacles* which are attached to rocks or other substances and build a protective covering of many calcareous

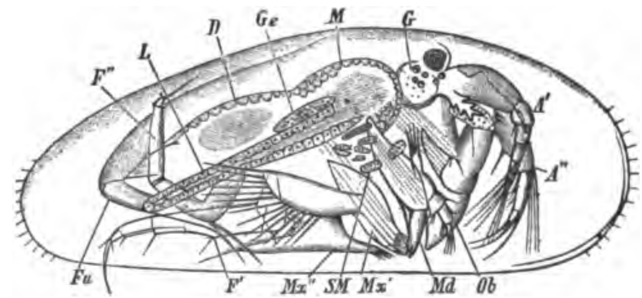


FIG. 926 *a*. — A modern ostracod (*Cypris*), showing the internal anatomy. Female before sexual maturity; right valve of shell removed to show internal anatomy. (*A'A''*, first and second pair of antennæ; *Ob*, upper lip; *Md*, mandible with leg-like feelers; *G*, cerebral ganglion with unpaired eye; *SM*, shell muscle; *Mx' Mx''*, first and second pair of maxillæ; *F'*, foot for crawling; *F''*, foot for cleaning; *Fu*, furka; *M*, stomach; *D*, intestine; *L*, liver; *Ge*, genitals.) (After Haas, *Leitfossilien.*)

pieces, the outer ring of which forms the cylindrical or conical " corona " of the typical acorn barnacle (Fig. 928). Other types of barnacles arrange their calcareous plates in diverse ways (Fig.

FIG 926 *b.* — *Palæocypris edwardsi*, Upper Carbonic, St. Etienne, France (much enlarged). The only fossil ostracod preserving the internal structures which are silicified. (*a*, Eye; *abd*, abdomen; *g*, genital organs; *k*, upper margin of body; *s*, shell with bristles on upper margin, incomplete behind; 1, antennulæ; 2, antennæ; 3, mandible; 4, premaxillæ; 5, maxillæ; 6, thoracic appendages.) (After Brongniart.)

929). Though typically Mesozoic and younger, representatives of this group also occurred in the Palæozoic.

Phyllocarida. — Still another group abundantly represented in the Palæozoic were the phyllocarids, which had a part of their body inclosed in a saddle-shaped shell or carapace (Figs. 930, 931).

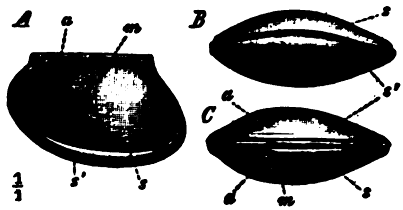


FIG. 927. — *Leperditia hisingeri*, Silurian, Gotland. *A*, left side; *B*, ventral side; *C*, dorsal view (*a*, eye spot; *m*, muscle spot; *s*, left valve; *s'*, right valve). (After Steinmann.)

Malacostraca. — This subclass includes a number of orders, of which the Amphipoda, Isopoda and Decapoda are the most familiar. The first of these orders is illustrated by the long, slender *Idotea* of the Atlantic beaches, and by the sow-bugs, pill-bugs, or wood-lice found under stones and logs. They are not positively known before the Tertiary. The Isopoda are represented by the common beach or sand-flea (*Orchestia*) of the present time and by fossil forms from the Jurassic on. Older types have also been referred to this order with some doubt.

FIG. 928. — The barnacle, *Balanus*, growing attached to a rock. (See also Fig. 790, p. 66.)

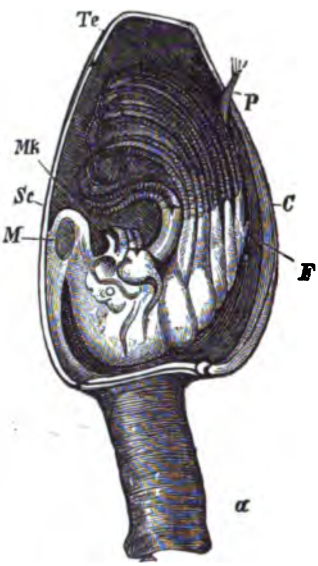


FIG. 929.—The Goose Barnacle, *Lepas anatifera*, with right valve removed. *a*, Stem; *C*, *Te*, and *Sc*, shell pieces (*C*, carina; *Te*, terga; *Sc*, scuta); *Mk*, mouth; *F*, furca; *P*, cirrus (or penis); *M*, muscle.

The group of the Decapods (lobster, crabs, etc.), with large jointed legs, and the head and thorax inclosed by a single shell piece or carapace, are primarily characteristic of the Mesozoic and younger rocks, continuing to the present time (Figs. 932, 933).

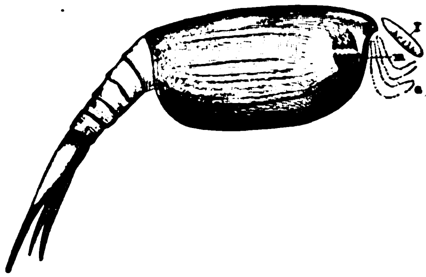


FIG. 930. — An Ordovician phyllocarid crustacean, *Ceratiocaris papilio* (× ⅓). Lanarkshire, Scotland. *a*, Antennæ; *m*, mandible; *r*, rostrum. (After Woodward.)

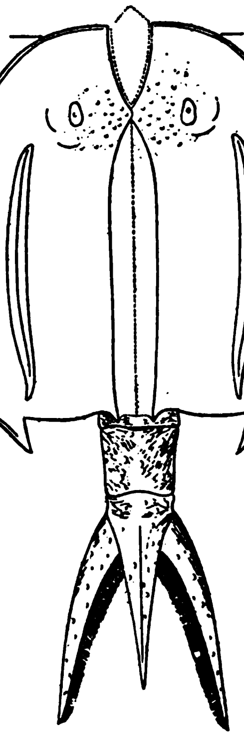


FIG. 931. — A Devonian phyllocarid crustacean, *Mesothyra oceani*. Portage shales of New York (× $\frac{3}{8}$). (After Hall and Clarke.)

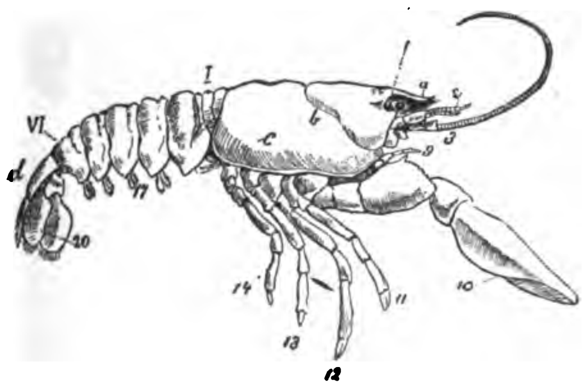


FIG. 932. — The Crayfish. Adult male. *a*, Rostrum; *b*, cephalothoracic shield; *c*, gill; *d*, anal segment; I–VI, abdominal segments; 1, eye stalk; 2, 3, feelers; 9, outermost jaw-foot (maxillipede); 10, chelate foot; 11–14, walking feet; 17, swimming feet (pleopoda); 20, caudal fin. (After Huxley.)

Acerata. — The oldest group of the Acerata appears to have been that of the *Merostomata*, which in the Palæozoic were represented

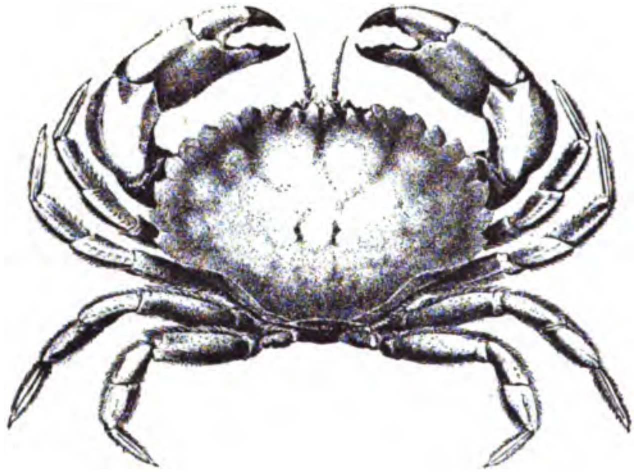
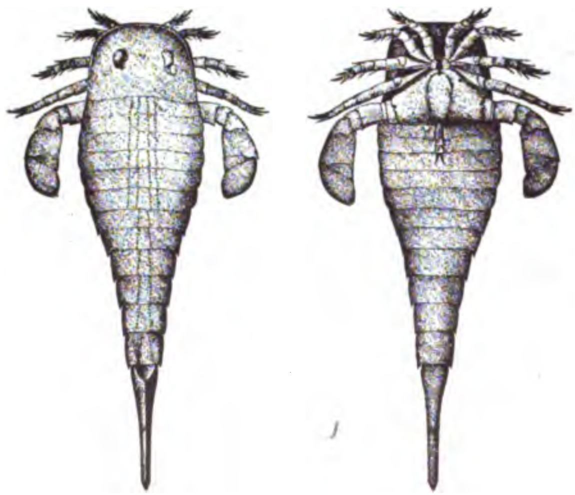


FIG. 933. — A recent crab (*Cancer antennarius*), from the Pacific coast (×½).

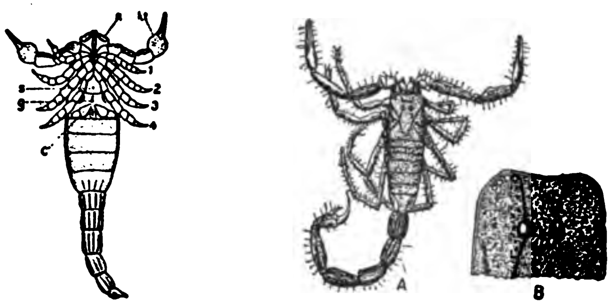
chiefly by the eurypterids, a group of crustacea-like animals, some of which reached a length of six feet or more. Their general appearance and character are shown in the annexed figures (Figs. 934 *a*, *b*). The



a *b*

FIG. 934. — A fossil merostome, *Eurypterus remipes*. Upper (*a*) and under (*b*) side of an individual, restored. (First pair of appendages omitted.)

entire body was covered with a lime-impregnated skin as in Crustacea, and as in these animals, this skin was shed repeatedly during growth. The anterior portion, or cephalothorax, carried a pair of



A *B*

FIG. 935. — Fossil scorpions. *A*, *Palæophonus caledonicus*, Upper Silurian, Scotland. Ventral side restored (1–4, walking legs; *c*, comb; *g*, genital opening; *k*, *kt*, feelers; *s*, sternum, natural size). (After Pocock.) *B*, *Tityus logenus;* Lower Oligocene amber; Samland. *A*, dorsal side, × 3; *B*, anterior part of cephalo-thorax; much enlarged. (After Menge.)

compound and a pair of simple eyes, and on its under side, besides the mouth-parts, six pairs of jointed appendages, the first with pincer-like termination, and the last often paddle-shaped. The first six segments of the ringed abdomen carried flat, leaf-like breath-

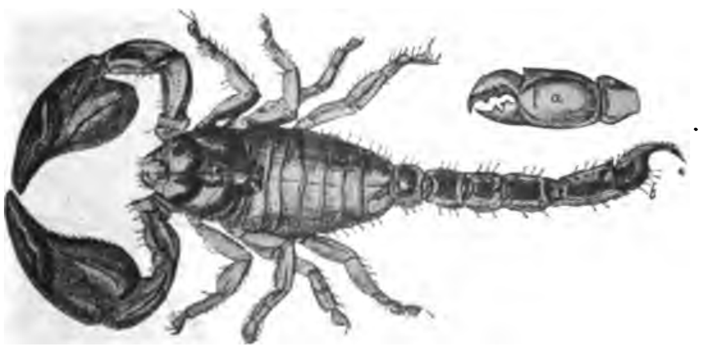


FIG. 936. — A modern scorpion, *Scorpio after* (natural size). *a*, Chela or pincer claw (enlarged); *b*, poison gland; *c*, poison sting.

ing organs or "gills," but the other rings and the terminal spine, or telson, were without appendages.

Recent studies seem to indicate conclusively that these organisms were inhabitants of the rivers of the Palæozoic. From them, it appears, the land *scorpions* arose, the oldest of which are known from the Upper Silurian deposits (Fig. 935 *A*). Examples of a

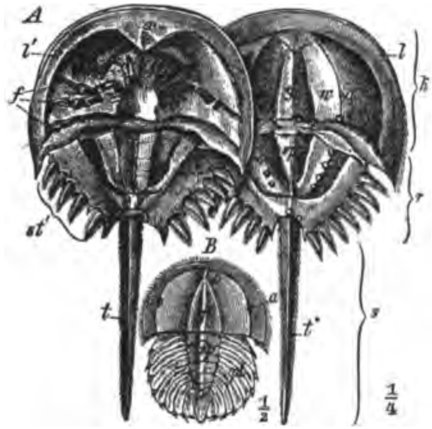


FIG. 937. — *A*, Jurassic horseshoe crab, *Limulus walchi*. Solnhofen. Ventral and dorsal views. One fourth natural size. *B*, *L. polyphemus*, the larval stage (trilobite stage) of the modern species; one half natural size; (*k*, cephalothorax; *r*, abdomen; *s*, caudal portion or telson (*t*); *gl*, glabella; *a*, compound eyes; *o*, simple eyes (ocelli); *w*, cheek; *l*, marginal rim; *x*, doublure; *st'*, marginal spines (normally 6); *f*, legs; *sp*, axis; *pl*, pleuræ). (After Steinmann.)

Tertiary and a modern scorpion are shown in Figs. 935 *b* and 936, respectively. The well-known horseshoe crab (*Limulus*, Fig. 937) of our sea-coasts is a modern representative of the merostomes

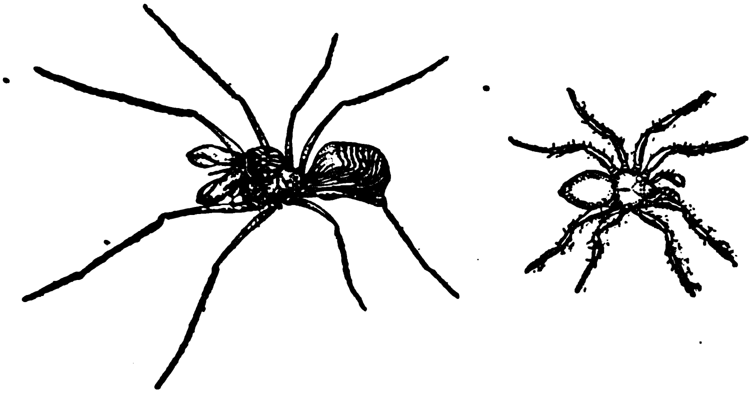


FIG. 938. — Oligocene spiders. *A*, *Archæa paradoxa*, Koch (× 3); *B*, *Mizalia rostrata*, Koch (× 3). Lower Oligocene amber. Samland. (After Zittel.)

and is also known from Mesozoic sediments. It had Palæozoic ancestors, which also seem to have lived in fresh water.

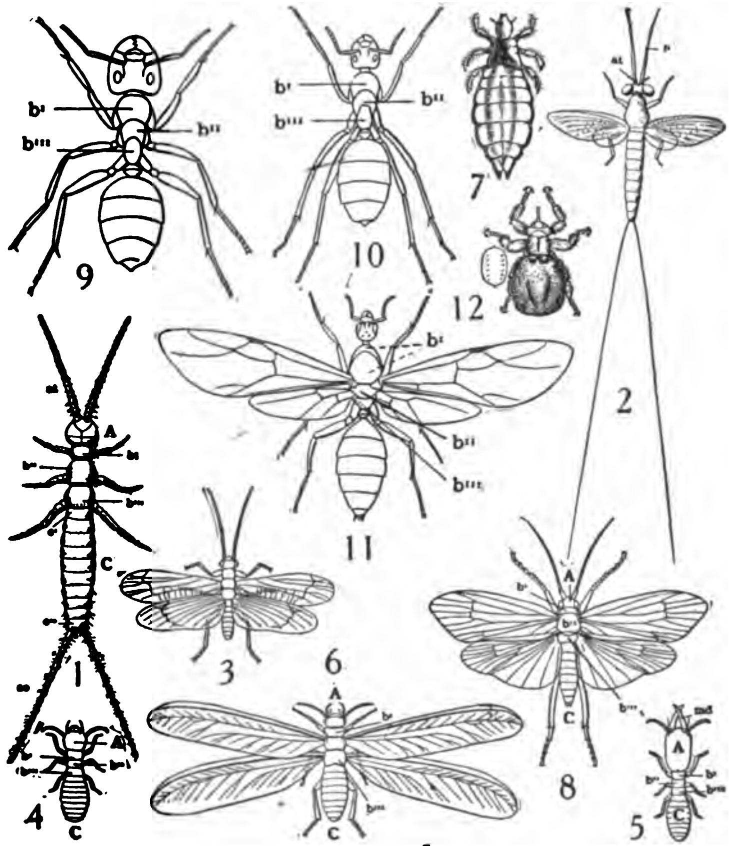


FIG. 939. — Modern types of insects. 1, Springtail (Thysanura, *Campodes*); 2, May-fly or Day-fly (Ephemeroptera, *Ephemera*); 3, Stone fly (Plecoptora, *Nemoura*); 4–6, Termites or white ants (Platyptera, *Termes*, enlarged): 4, worker; 5, soldier; 6, king or perfect male; 7, human louse (Hemiptera (Heteroptera), *Pediculus*, enlarged); 8, Caddis-fly (Trichoptera, *Anabolia*); 9–11, ants (Hymenoptera, *Formica*): 9, soldier; 10, worker; 11, winged male; 12, sheep tick (Diptera, *Melophagus*). All figures slightly reduced except 3 which is slightly enlarged; 4, 5, and 12 which are twice natural size; and 7 which is four times natural size. In all of the figures: *A*, head; *B*, thorax; *C*, abdomen; *at*, antennæ; *b'*, prothorax; *b''*, mesothorax; *b'''*, metathorax; *c'–c''*, abdominal segments; *se*, thread-like setæ.

The *spiders*, which with the scorpions form the subclass *Arachnida*, include several thousand modern species. They appeared first in the period of the Coal-measure forests (Carbonic), but may have existed previously. The head and thorax are united into a cephalothorax, while the abdomen is distinct but without rings.

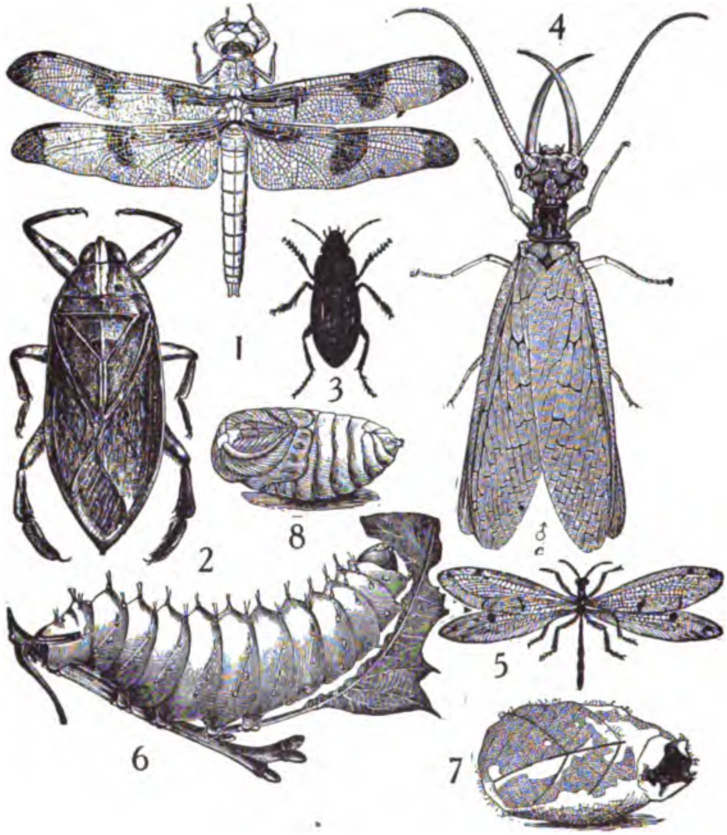


FIG. 940. — Modern types of insects. (All about $\frac{5}{7}$ natural size.) 1, Dragon fly (Odonata, *Libellula*); 2, Giant water bug (Hemiptera (Heteroptera), *Belostoma*); 3, Carabid beetle (Coleoptera, *Harpalus*); 4, Crawler (Neuroptera, *Corydalus*), reduced; 5, Ant-lion (Neuroptera, *Myrmeleon*); 6–8, American silk-worm (Lepidoptera, *Telea polyphemus*); 6, Caterpillar; 7, Cocoon with larva; 8, Pupa. (For moth see Fig. 941.)

Beautifully preserved individuals are found in the Oligocene amber of the Baltic (Figs. 938 *A*, *B*).

Insecta. — These arthropods, of which there are now over 384,000 living species, appear to have arisen from some trilobite ancestor during a period of land expansion, when a premium was put upon the ability of the animal to breathe air in some direct way. The

FIG. 941. — A modern moth (Lepidoptera, *Telea polyphemus*).

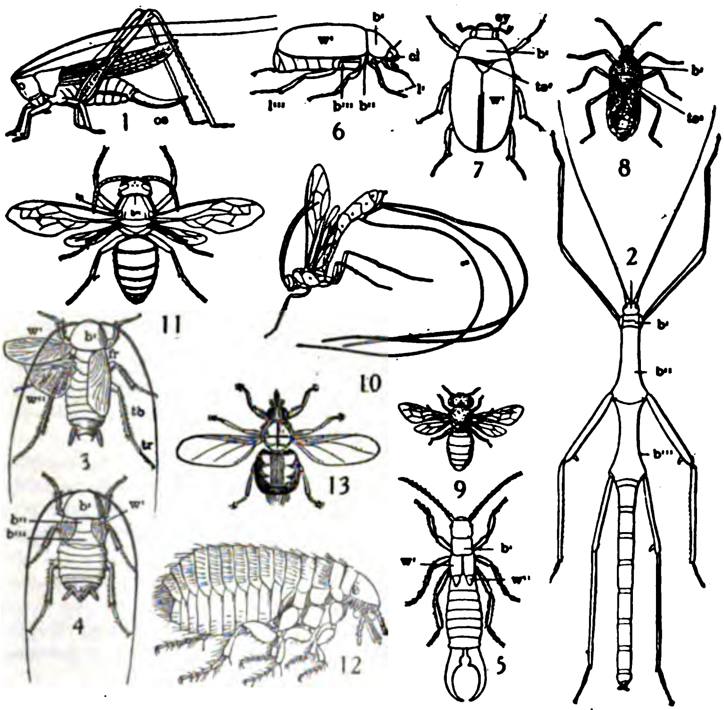


FIG. 942. — Types of modern insects. 1, Grasshopper (Orthoptera, *Orchelinum*); 2, walking-stick (Orthoptera, *Diapheromera*); 3, 4, cockroach (Orthoptera, *Periplanata:* 3, male; 4, female); 5, earwig (Dermoptera, *Forficula*); 6, 7, May-beetle (Coleoptera, *Lachmosterna*, side and top view); 8, squash-bug (Hemiptera, *Anasa*); 9, honey-bee (Hymenoptera (*Apis*, worker); 10, Ichneumon-fly (Hymenoptera, *Thalessa*); 11, paper or social wasp (Hymenoptera, *Vespa*); 12, flea (Siphonoptera); 13, forest-fly (Diptera, *Hippobosca*). All figures reduced one half except 12, which is twice enlarged.

group probably arose in the Ordovician, but did not become prominent until the period when the Coal-measure forests flourished. Even then insects were of an archaic type, though often large, and resembling in general form some modern species. The modern

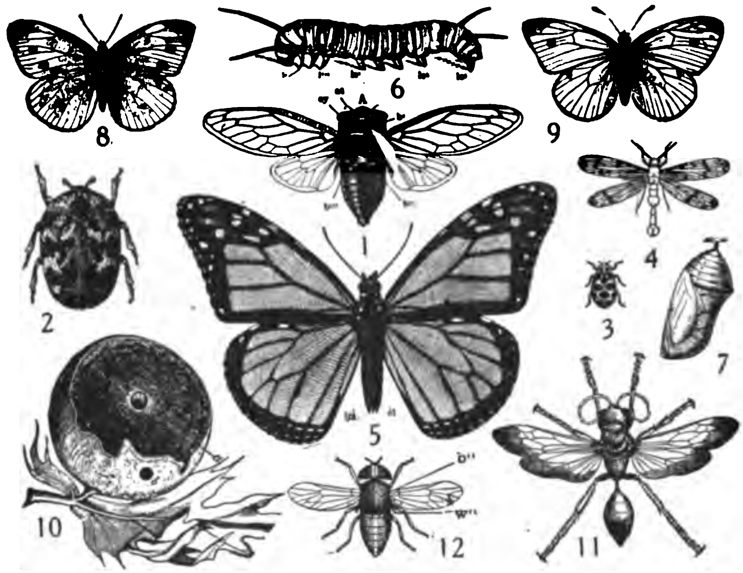
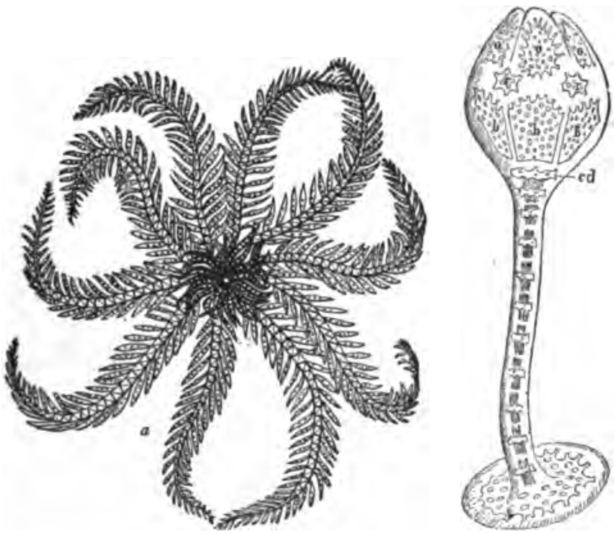


FIG. 943. — Types of modern insects. (All reduced about one half except 2, which is greatly enlarged, and 3, which is natural size.) 1, Cicada or harvest fly (Homoptera, *Cicada*); 2, Buffalo or carpet beetle (Coleoptera, *Anthrenus*, greatly enlarged); 3, lady-beetle or lady-bug (Coleoptera, *Megilla*); 4, Scorpion-fly (Mecoptera, *Panorpa*); 5–7, milkweed butterfly (Lepidoptera, *Danais:* 5, male; 6, caterpillar; 7, chrysalis or pupa); 8–9, cabbage butterfly (Lepidoptera, *Pieris:* 8, female; 9, male); 10, oak gall or oak apple broken to show the larva of the gall-fly in its cell (Hymenoptera, *Cynips*); 11, digger wasp (Hymenoptera, *Sphex*); 12, horse-fly (Diptera, *Tabanus*). In 1: *at*, antennæ; *ey*, compound eye; b', prothorax; b'', mesothorax; b''', metathorax. In 6: l'–l''', true, jointed legs; ls^1–ls^4, unjointed, false legs or prop-legs; ls^5, prop-legs on last or thirteenth segment. In 10: *a*, larva; *b*, opening through which winged insect emerges. In 12: b'', mesothorax; w'', point of insertion of one of the small second pair of wings.

insects arose in the Mesozoic, and their great development appears to be correlative with the spread of flowering plants over the lands. In modern insects the head, thorax, and abdomen are distinct, the head carrying mouth parts, antennæ, eyes, etc., while the thorax is typically furnished with three pairs of legs (hence the name Hexapoda — six-footed) and two pairs of wings, one or both of which may be modified or absent altogether. Breathing is accomplished by a series of respiratory tubes (trachea) which open externally permitting the direct entrance of the air. The principal orders of modern insects are represented in Figs. 939–943.

Echinodermata. — These are all marine animals with a body protected by a series of calcareous plates more or less closely associated and formed within the outer integument of the body. Three of the orders — cystoids, blastoids, and crinoids — are usually fixed to the sea-bottom by a flexible stem or by direct attachment



A *B*

FIG. 944. — An unattached modern crinoid, *Comatula*. *A*, Adult (reduced; after Forbes); *B*, stalked "Pentacrinoid," larval stage (much enlarged; after Wyville Thomson); *b*, basals; *r*, radials; *o*, orals; *cd*, centrodorsal plate.

to other objects. Some forms, however, are free (Figs. 944 *A*, *B*). The other four classes are free and have the power of locomotion.

Crinoids. — (Figs. 944–946.) The stem of a crinoid is typically composed of a series of calcareous disks, superposed, and held together by organic tissue. The center of the stem is pierced by an axial canal. The stem is sometimes fixed by an expanding basal disk, by root-like branches, or it is buried in the mud. In the Mesozoic and modern crinoids certain of the stem elements have short lateral branches or cirri, which give the stem a very characteristic aspect (Fig. 946). The body of the crinoid consists of a regular series of plates in close juxtaposition, and of definite form and number for each genus and species (Fig. 947). They are generally arranged in circles of five, but an additional series may become interposed on one side (anal series, Fig. 947 *D*, a_1–a_6). The circles of plates are successively designated as *basals*, of which there may be two circles, the plates alternately arranged, and as *radials*, which alternate in position with the plates of the basal ring next below. Above

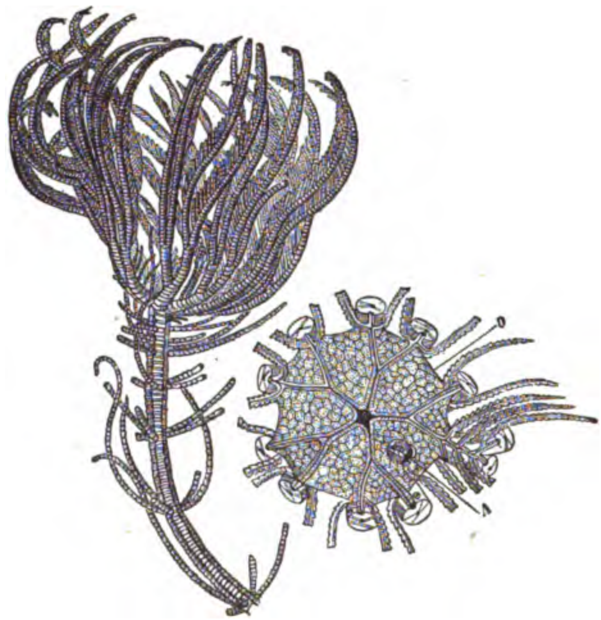


FIG. 945. — A modern deep-sea crinoid, *Pentacrinus caput-medusæ*, Miller. Calyx with arms and part of stem. Oral surface of calyx enlarged. *O*, mouth; *A*, anus. (After J. Müller.) (Note distant cirri of stem as compared with crowded character in the fossil species, Fig. 946.)

the radials are the arm plates (*brachials*), which may articulate with the radials, producing "free" arms, or, as in most of the Palæozoic forms, are closely joined to the other plates for several successive circles, after which the arms become free (Fig. 947 *A*, *br*). A cup or *calyx* is thus formed, the top of which is covered by a membrane or by a series of closely arranged but irregular plates, and these may extend into a proboscis or tube, at the end of which the anal opening is situated (Fig. 947 *A*, *pr*). The mouth is beneath the calyx cover, and from it grooves or canals lead to the arms

(Fig. 947 *C*). These are five in number, but may branch repeatedly. They are composed of a succession of calcareous plates embedded in organic material, each plate being provided on alternate sides with a small branch or pinnule of construction similar to that of the arm (Fig. 946). The food is gathered by these pinnule-bearing arms from the sea-water (plankton) and conveyed along a median groove to the mouth. (See also Fig. 945 *o*.)

FIG. 946. — *Pentacrinus* from the Jurassic. (Note the crowded character of the cirri upon the stem and compare with their distant arrangement in the modern form, Fig. 945.) (After Kirk.)

Cystoids and Blastoids. — In the *cystoids*, which constitute the oldest division of the stemmed echinoderms, the plates are irregular, not in series, the arms few or aborted, and the stem sometimes absent (Fig. 948). A peculiar series of pores and canals covers the plates or is restricted to certain areas. These pores serve in part a breathing function. The *blastoids* (Fig. 949), which are most abundant in the later Palæozoic, have no arms, but each radial plate is incised, this incision being occupied by a grooved plate or a plate margined by many small additional plates with pores between (Fig. 950 *b*). This is the so-called "ambulacral area" and from its margins pinnules may arise. These are, how-

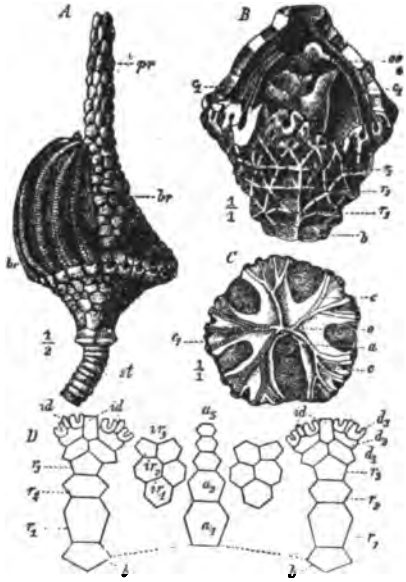


FIG. 947. — The structure of crinoids. *A*, *Lobocrinus pyriformis*, Mississippian (*br*, arms, removed on one side; *pr*, proboscis; *st*, stem); *B*, *Cactocrinus proboscidalis*, with covering partly broken (c_1, ambulacra); *C*, internal mold of same (*a*, arms; *c*, branching ambulacra; c_1, small covering plates of ambulacra; *o*, mouth); *D*, Calyx plates of *Batocrinus* (*b*, basals; r_1, radials; r_2, r_3, primary brachials; d_1–d_2, secondary; d_3, tertiary brachial; a_1–a_6, anal interradials; ir_1–ir_3, interbrachials; *id*, higher interbrachial). (After Meek and Worthen.)

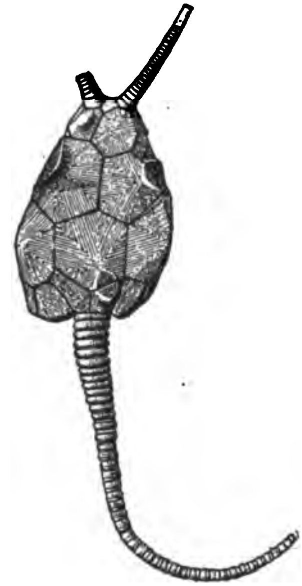


FIG. 948. — A typical cystoid, *Pleurocystites squamosus*, with nearly entire stem and broken arms. Note the three pore rhombs (hydrospires), the raised rhombic areas marking the junction of three plates.

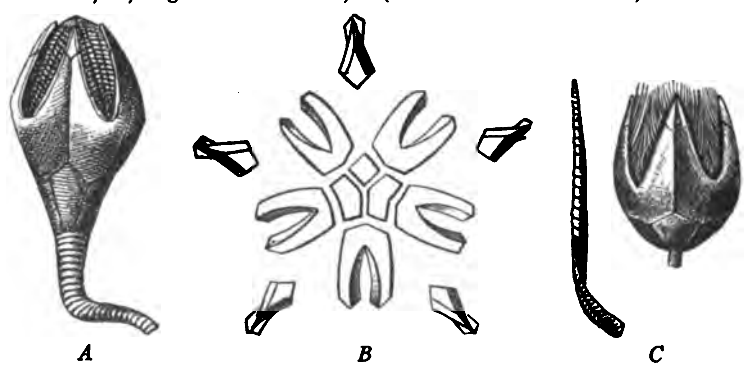


FIG. 949. — *Blastoids*. *A*, *Pentremites pyriformis* with stem; *B*, *P. florealis*, separated plates; *C*, *P. sulcatus*, showing pinnules, one of which is enlarged. Mississippian (Chester) limestones.

ever, seldom preserved. The breathing apparatus consists of folded sacs on the inside of the ambulacral areas (Figs. 950 *b*, *hy*,

FIG. 950 *a*. — Reconstruction of a blastoid, *Orophocrinus fusiformis*. Mississippian, of Iowa; about natural size. (*W*, hold-fast; *St*, stem; *B*, basals; *G*, radials with deltoids; *Pi*, pinnules covering ambulacra.) (After Bather.)

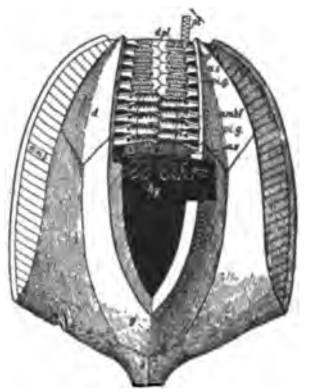


FIG. 950 *b*. — A prepared blastoid calyx, *Pentremites godoni*, showing structure. (*b*, basals; *g*, radials; *d*, deltoids. Central ambulacral area with parts removed showing: *dpl*, covering plates; *hy*, hydrospires; *l*, lancet plate; *p*, pores between side plates; *pi*, biserial pinnule; *pi.g*, pinnule groove.) Upper Mississippian (Chester) beds of North America. (After Oehlert.)

and 951), communicating with the exterior by ambulacral pores, and generally opening by apertures or slits placed around the central mouth. The anal opening may be distinct (Fig. 952), or

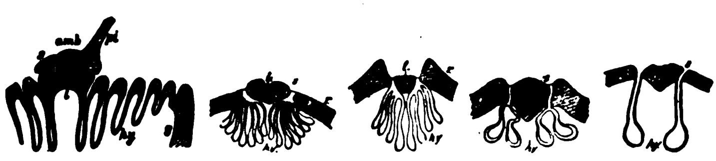


FIG. 951. — Hydrospire types of blastoids. *a*, *Codaster trilobatus*; *b*, *Orophocrinus verus*; *c*, *Mesoblastus lineatus*; *d*, *Orbitremites norwoodi*; *e*, *Orbitremites derbyensis* (*amb*., ambulacral groove with covering plates; *hy*, hydrospires; *l*, lancet-plate with axial canal; *pi*, pinnule; *r*(*g* in *a*) margin of deltoid; *s*, side plates). (After Etheridge and Carpenter.)

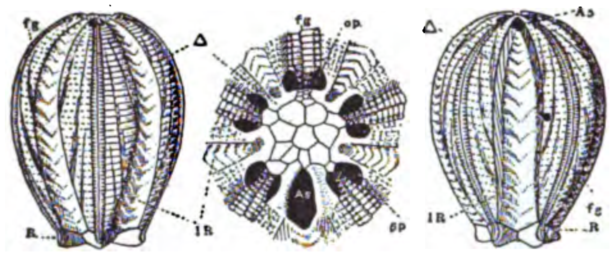
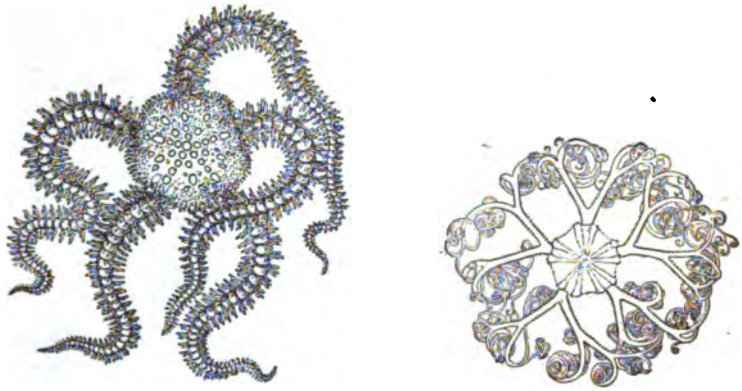


FIG. 952. — A Middle Devonian blastoid, *Elæacrinus verneuili*. Columbus, Ohio. *a*, anterior view; *b*, oral view; *c*, posterior (anal) view. (*As*, anus; *cp*, covering plates; *fg*, ambulacral furrow; *IR* and Δ, interradials or deltoids; *R*, low radials; *sp*, spiracula. (After Bather.)

FIG. 953. — Modern starfish (*Astropecten spinulosus*) in natural surroundings. The upper figure shows the dorsal surface with the *madreporic body* in the center between the two arms; the lower figure shows the ventral surface with the mouth in the center, and the minute " tubed feet " or ambulacra along the center of each ray. (After Heck, etc., *Das Tierreich.*) See also Figs. 788–790, pp. 64–65.



A *B*

FIG. 954.—Modern types of Asteroidea of the North Atlantic. *A*, Brittle star (*Ophiopholis aculeata*); *B*, Basket star-fish (*Gorgonocephalus agassizii*) reduced.

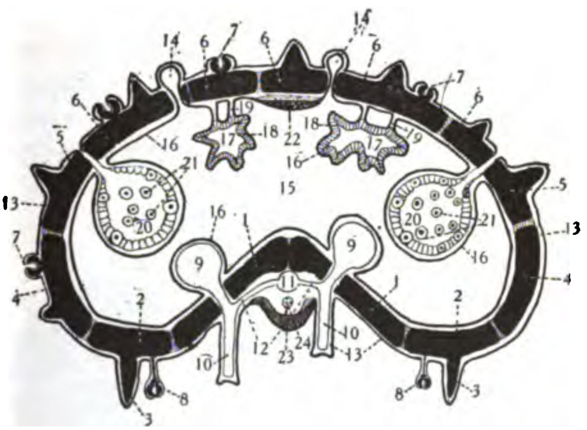


FIG. 955 *a*.—Semi-diagrammatic cross section of the arm of a starfish. The various parts represented are as follows: 1, ambulacral plates; 2, ad-ambulacral plates; 3, moveable spines of same; 4, infra-marginal plates with solid spines; 5, supra-marginal plates with solid spines; 6, dorsal plates with solid spines; 7, sessile pedicellaria; 8, stalked pedicellaria; 9, ampulæ or sacs of the water-vascular system; 10, tube-feet or ambulacra; 11, radial canal of the water-vascular system; 12, connecting canals of the water-vascular system; 13, ectodermal fleshy layer surrounding the entire body including the spines, pedicle area and the ambulacra; 14, breathing vesicles or branchiæ; 15, body or cœlom (brachial extensions of the same); 16, endothelium or inner lining of the body cavity; 17, extensions of the stomach cavity into the arms (brachial diverticula from the stomach); 18, endodermal layer of the stomach branches; 19, supporting mesenteries of the stomach branches; 20, gonads or reproductive branches (ovarium); 21, ova; 22, nerve ridge of apical nervous system; 23, radial nerve ridge of the superficial oral system; 24, continuation of the axial organ in the arm. (Original.)

fused with the respiratory pores on one side as in *Pentremites*. The name blastoid refers to the bud-like appearance of some forms (*Pentremites*, etc.). Cystoids and blastoids are restricted to the

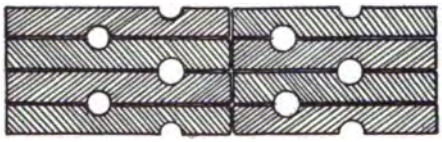


FIG. 955 *b*. — Diagram of a few of the ambulacral plates of a starfish arm seen from below to show their arrangement and the manner in which adjoining plates are grooved to make the ambulacral pores, for the extension of the tubed feet. (Original.)

Palæozoic. Crinoids continue to the present time, but are to-day mostly found in deep water. In the Palæozoic they probably lived in shallow water.

Asteroidea and Ophiuroidea. — These comprise the starfish (Fig. 953) and the brittle stars (Fig. 954 *a*). They are characterized by five arms or rays (which, by branching, in some of the latter groups may become multiple, Fig. 954 *b*). The upper side is rendered firm by

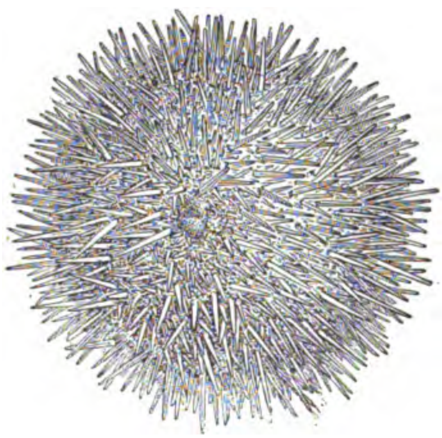


FIG. 956. — *Strongylocentrotus dröbachiensis*, the common sea-urchin of the North Atlantic, top view.

plates or a network of rods embedded in the skin, while the under side of each ray is characterized by an ambulacral area, consisting of rows of small plates placed side by side with grooves between, through which delicate tubes terminating in sucking disks (the *ambulacra*) project, by means of which the animal holds fast in walking (Figs. 955 *a*, *b*). The mouth is in the center of the under side, while between two rays, usually on the upper side, is a porous body (madreporic body) which admits water to a complex system of internal tubes, which finally terminate in the sucking feet or

FIG. 957. — The shell or *corona* of a sea-urchin (*Echinus*), broken open so as to show the interior with the dental apparatus (Aristotle's lantern) in place, and showing the arrangement of the plates.

ambulacra. This entire system is called the water-vascular system, and serves for respiration and locomotion in typical starfish.

Echinoidea. — The echinoids (Fig. 956) or sea-urchins build a solid structure (corona) of plates of subspherical, somewhat disk-shaped or elongate, and variously modified, form. Ten meridional zones of plates are recognizable, passing from the mouth-opening

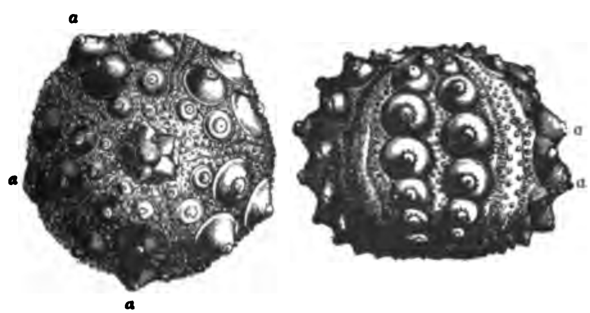


FIG. 958 *a*. — A Cretaceous echinoid, *Hemicidaris crenularis*; top and side view. (*a*, mamellar knobs marking place of attachment of the movable spines, which have all been detached in the specimen shown.)

on the under side to the top of the corona, where the anal opening is situated in the regular forms. In the majority of regular echinoids each zone is composed of two columns of plates placed alternately in position with a zigzag junction between the two columns (Fig. 957). Each alternate zone has its plates pierced by two or more holes, through which long, slender ambulacra, like those of the starfish, project. These are the ambulacral zones. In alternate zones (interambulacral) the plates bear movable spines, each set upon a knob or *spine boss* (Figs. 958 *a*, *b*). The mouth is supplied with a complicated dental apparatus (Aristotle's lantern, Fig. 959), and around the upper (anal) end there are ten plates, alternately with large and with small pores (Fig. 960). Five of these are eye plates, the pores being furnished with pigment masses which react to light, and five are genital plates, the pores serving for the emission of the reproductive products. In the late Palæozoic echinoids the zones consisted generally of more than two columns, often ten or more, and the junction of the plates was commonly less rigid than in later types, so that the original form is often distorted in the sediments (Fig. 961). In the Mesozoic and younger deposits, many "irregular" echinoids occur. The simplest of these still have the mouth in the center of the under side, but the anus is no longer at the top, having

FIG. 958 *b*. — An echinoid spine from *Cidaris glandiferus*; natural size.

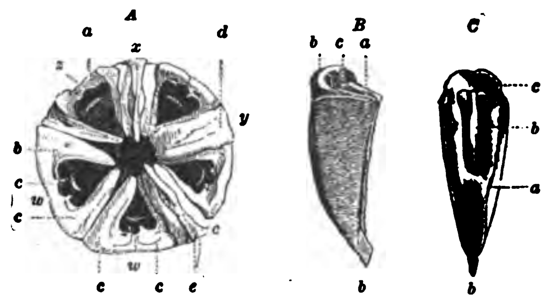


FIG. 959. — Dental apparatus, "Aristotle's lantern," of a sea-urchin (*Sphærechinus*). *A*, View of the flat upper surface, showing the supporting pyramidal plates (*a*) and connections (*b*, *c*, *e*, *w*, *x*). *B*, *C*, Half-pyramids seen sidewise and from within, showing lateral wings (*a*), one of the five enameled teeth (*b*), and one of the connecting processes (*c*). For position of the dental apparatus in the shell, see Fig. 957. (From Zittel, *Grundzüge*.)

moved along a line which marks the median axis and the direction of elongation of the corona (Fig. 962). Here, then, bilateral symmetry is strongly marked and is further emphasized in some forms by the forward movement of the mouth along the same line and by the form of the test as a whole (Fig. 963). In these more specialized types, which range from flattened disks (sand-dollar)

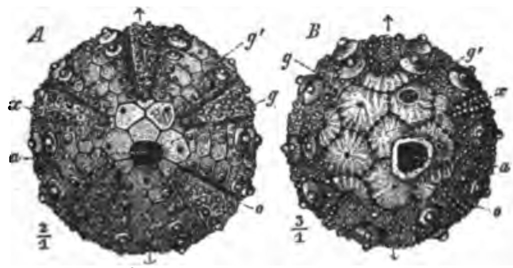


FIG. 960. — Dorsal views of two echinoids, showing the apical systems of plates and the anal openings. *A*, *Acrosalenia sinosa*, Jurassic; *B*, *Salenia prestensis*, Cretaceous (*a*, anal aperture; *x*, central plate; *o*, eye (ocular) plates; *g*, genital plates; *g′*, madreporic body). The arrows mark the planes of symmetry. (From Steinmann.)

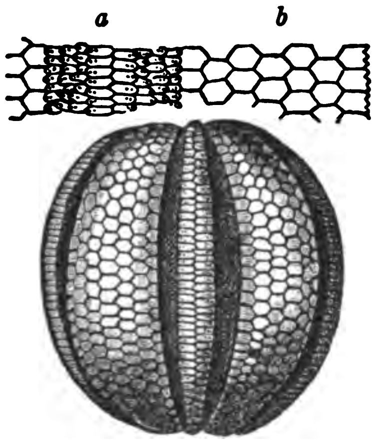


FIG. 961. — A Palæozoic sea-urchin (*Melonites multiporus*) Mississippian (St. Louis limestone), Missouri. The details of an ambulacral (*a*) and an inter-ambulacral (*b*) area are shown in the upper figure.

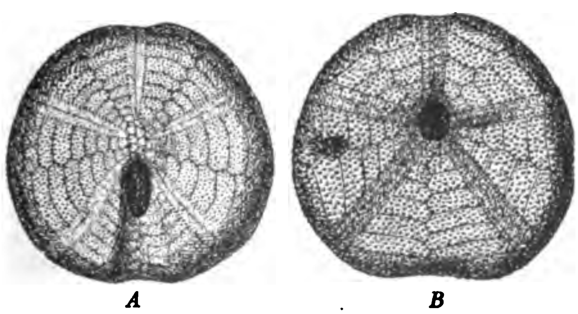


FIG. 962. — Middle Jurassic echinoid (*Hyboclypeus gibberulus*), France. *A*, from above; *B*, from below. (After Cotteau.)

to heart-shaped form, the pores in the plates of the ambulacral zone are generally restricted to the upper side, while the spines are mostly small and slender.

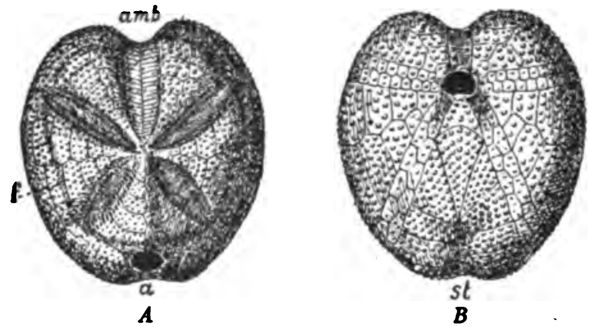


FIG. 963. — Upper Cretaceous echinoid (*Hemiaster meslei*), Cenomanian, Algiers. *A*, from above; *B*, from below (*a*, anus; *amb*, anterior ambulacrum; *f*, lateral fascioles; *st*, sternum). (After v. Stromer.)

FIG. 964. — A modern holothurian (*Cucumaria crocea*), with its young attached to its skin. (Challenger.)

Holothuroidea. — In the holothurians or sea-cucumbers (Figs. 964–966), which range from sausage to foot-ball form, the plates in the skin are not in juxtaposition, but separately embedded. On

FIG. 965. — A modern holothurian (*Lophothuria fabricii*).

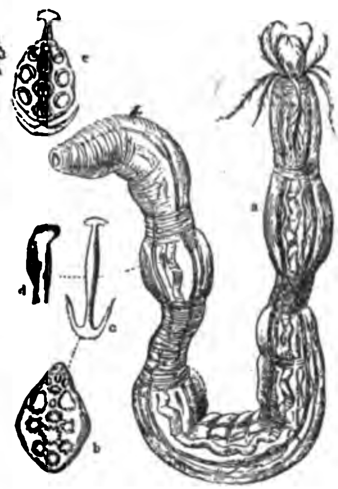


FIG. 966. — A modern holothurian (*Synapta inhærens*). *a*, complete animal; *b–e*, calcareous particles and plates of *S. besselii*, enlarged. (After Heck.)

the death of the animal they separate, and are generally included in a scattered condition in the sediment (Fig. 966).

Vertebrata. — These include the *ostracoderms* (extinct fish-like animals with their bodies covered by plates, Fig. 967) and *fish* (Figs.

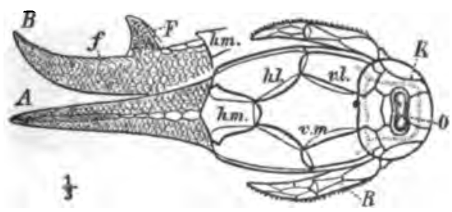


FIG. 967. — A Devonian armored fish-like ostracoderm, *Pterichthys cornutus*, restored. Old Red Sandstone, Scotland. *A*, dorsal aspect; *B*, lateral view of tail.

F, dorsal fin; *K*, head; *O*, unpaired (orbital) opening; *R*, paddles; *f*, median scales; *hl*, posterior dorso-lateral plate; *hm*, posterior dorso-median plate; *vl*, anterior dorso-lateral plate; *vm*, antérior dorso-median plate. (From Steinmann.)

969–971 *b*) as the typical aquatic members, the latter occupying both fresh and salt water at the present time, but apparently confined to fresh water in the earlier Palæozoic, as were the ostracoderms.

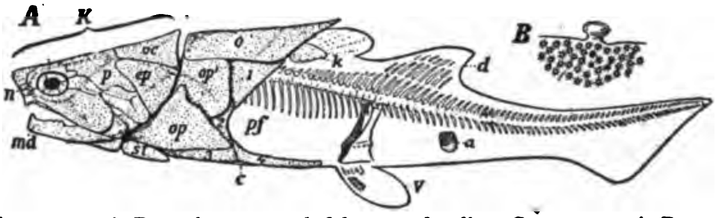


FIG. 968. — A Devonian armored fish or arthrodire, *Coccosteus*. *A*, Reconstruction ($\times \frac{3}{7}$).

K, head: *n*, nasal openings; *md*, lower jaw; *p*, parietal; *o*, occipitals; *ep*, epioticum; Neck region (*o*, cervicals; *op op'*, opercula; *st*, movable spine; 1–4, elements of the shoulder girdle (*c*); *k*, basal plate of anterior dorsal fin); *d*, dorsal fin; *a*, support of anal fin; *v*, ventral fin, attached to simple pelvis; *pf*, region of anterior ventral fin. *B*, upper operculum (*op'*) ($\times \frac{9}{10}$). (After Steinmann.)

The *amphibians* usually pass their youthful stages in water, breathing by means of gills (tadpole stage, Fig. 972). Some forms remain permanently in this state, but others (frogs, salamanders) leave

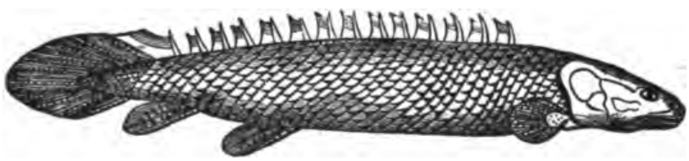


FIG. 969. — The modern *Polypterus* of the Nile. (Reduced.)

the water when adult and breathe by means of lungs. The extinct order of Stegocephalia included some of the largest animals of this group. They ranged from the Mississippian to the Triassic. The

FIG. 970 *a*. — The modern mud-fish (*Epiceratodus forsteri*) of the rivers of Tasmania. $\frac{1}{14}$ natural size. (After Günther.)

first fossil skeleton of an amphibian was found in the Upper Miocene fresh-water deposits of Oeningen in Baden, and was described by the mathematician and medical practitioner, Johann Jakob

Scheuchzer in 1726 as "the sorrowful skeleton of an old sinner" a *homo diluvii testis*, witness of the deluge in Noah's time. Cuvier recognized it as the skeleton of a giant salamander (Fig. 973).

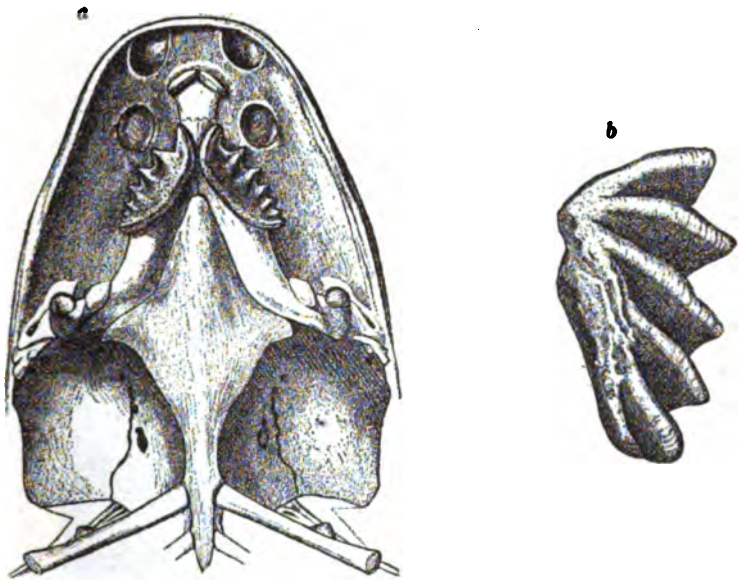


FIG. 970 *b*. — The skull of *Epiceratodus forsteri*, seen from below, with teeth in place; natural size. (After Günther.) *b*, Tooth of *Ceratodus runcinatus*, Triassic of Württemberg. $\frac{3}{4}$ natural size. (After Zittel.)

The *reptiles* are cold-blooded, four-legged vertebrates which usually develop from eggs as do birds, and breathe by lungs throughout

FIG. 971 *a*. — Modern Port Jackson shark (*Cestracion phillippi*), from Australia; much reduced. (After Le Conte.)

life. The body is covered with scales or plates instead of hair. Among the living types are the crocodiles, turtles, lizards, and snakes, and among the extinct types the rhynchocephalians (beakheaded reptiles) with one living representative (*Hatteria*), the theromorphs (beast-like reptiles), plesiosaurs, ichthyosaurs (fish-

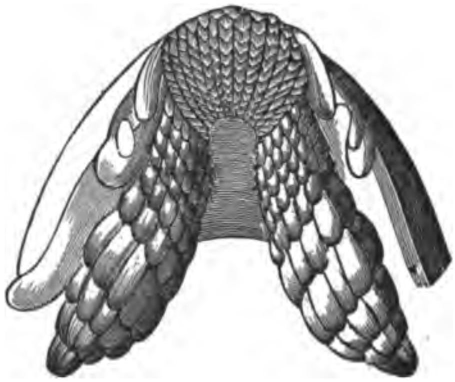


FIG. 971 *b*. — Dental plate of *Cestracion phillippi*. (After Le Conte.)

FIG. 972. — The life history of the frog. (After Thompson.) The fertilized eggs are shown among the seaweed. As the larva develops it feeds first on its own yolk (large round mass at left of illustration), then as it develops into the tadpole stage it feeds on plants and small animals. The tadpole at first has gills and a fish-like appearance; the gills are absorbed and lungs become active; hind legs appear; the tail is absorbed into the body and finally the metamorphosis is complete and the frog emerges on land as a four-footed air-breather.

like reptiles), dinosaurs (terrible land reptiles), and pterosaurs (flying reptiles). These will be more fully described in connection with the periods in which they lived.

Birds are warm-blooded, air-breathing animals which have their anterior limbs modified into organs of flight (wings) and their bodies

Fig. 973. — *Andrias scheuchzeri*, Upper Miocene, Oeningen, Baden. (Scheuchzer's original.) Ventral side, Cuvier's preparation. ($\frac{1}{8}$ natural size; after Zittel.)

covered with feathers. They reproduce from eggs. The oldest known bird (*Archæopteryx*, of the Jurassic, Fig. 1639) was very

Fig. 974. — Karl A. von Zittel (1839–1904). The " Father " of modern palæontology. Author of the leading reference and textbooks in the science and of many important monographs.

reptile-like, and there is every reason for believing that birds are derived from reptilian ancestors. In the Mesozoic era birds had teeth, but these are absent in the modern types.

Mammals are four-limbed, warm-blooded, air-breathing animals which, with the exception of a few lowly types, bring forth their young alive. The body is covered with hair and the teeth are differentiated into incisors, canines, premolars, and molars. There are also many other anatomical features which distinguish mammals from other vertebrates. Mammals first appeared in the later Mesozoic and in Tertiary time and became the dominant form of life. Man, the highest mammal, appeared toward the close of the Tertiary.

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CHAPTER XXVIII

THE BEGINNINGS OF EARTH HISTORY

We are now prepared to consider in outline the successive stages in the development of our earth, and to note the progress of life upon it as this is revealed to us by the fossils preserved in the rocks. Where and how life began upon this earth, whether it originated here from inorganic matter, as some hold, or was brought to the earth from some other planet, is at present a subject for speculation. There may have been a period when the earth was without life, that is, in an azoic condition, but it is certain that the higher forms of life, as we know them, could not appear until the earth had an atmosphere capable of maintaining them. Nevertheless, there are lowly organisms, such as some bacteria, which can exist where atmospheric air is excluded (anaërobic), and forms of this type may have existed upon the earth in the earliest times.

Our earth is one of the planets of a particular solar system, and there are many such solar systems in the universe. The development of these systems and of the individual planets in them is astronomical history, and before the geological history of our earth began there was a long period of time the history of which properly belongs to the domain of astronomy. Nevertheless, it seems desirable to give a brief outline of it so far as our earth is concerned.

The geological history of the earth began when the forces of construction, destruction, and reconstruction, which are now operative, first came into play: in other words, when the earth's solid framework was established and it had received its atmosphere and its ocean waters. It was at this period that the development and differentiation of life took place, though it is not possible to correlate the beginnings of organic evolution with the beginnings of the geological history of the earth.

A broad view of geological history enables us to recognize three great outstanding developmental periods, the pre-Palæozoic, the

Palæozoic, and the post-Palæozoic. The base of the Palæozoic, as generally recognized (the Cambrian), forms a natural line of demarkation from which we can carry our studies downward into the oldest rocks of the earth, and those studies have already revealed a succession of developmental stages which, in the aggregate, appear to have occupied a time interval far exceeding in length that of Palæozoic and post-Palæozoic time combined. Nevertheless, the studies of the pre-Palæozoic rocks and the history which they record have only been begun, and at present we can devote only a single chapter to their discussion. As geological investigation progresses, this portion of the earth's history will become more fully revealed, and in the future it will be necessary to pay increased attention to it.

The Palæozoic portion of the earth's history, on the other hand, has become known with some degree of fullness, although we are far from having deciphered it in its completeness. Its record is most completely preserved in the rocks of North America, and it is primarily by the labors of geologists in this field that this history has been uncovered. From what has become known so far, we begin to realize that the Palæozoic era of the earth's history was unique. Physical conditions, vastly different from those found to-day, existed at that time, and although the life of the era was developed from the survivors of the preceding one, and furnished survivors from which the organic world of the next younger eras was developed, yet, on the whole, the organisms of the Palæozoic were peculiar to it and their history constituted a closed or almost closed chapter in the life record of the earth. Not so with the succeeding post-Palæozoic or Neozoic time, in the latter part of which we ourselves exist. For although this portion is divisible into Mesozoic, Cenozoic, and Psychozoic eras, these appear to form a connected sequence, and the essential physical conditions which govern the development of the earth at the present time came into existence at the opening of the Mesozoic. It is true that there were many changes in the distribution of land and water and of climate as well, yet none of these changes appear to be as marked as were those which closed the pre-Palæozoic or the Palæozoic eras. Nor was the change in the character of the life as pronounced at any time as it was at the end of the Palæozoic. True, whole dynasties, such as those of the dinosaurs, of the ammonoids, etc., arose in the Mesozoic and disappeared at its close with surprising abruptness. Also, the ancestors of many Mesozoic forms are found in the later Palæozoic. Nevertheless, the change from Mesozoic to Cenozoic time is, on the whole, less abrupt than that which took place at the end of the Palæozoic. These facts will appear more fully as we proceed. Before entering upon this discussion, however, we must briefly outline the pre-geological history of the earth.

CHAPTER XXIX

THE PRE-GEOLOGICAL STAGES OF EARTH HISTORY

ALTHOUGH many theories of the origin of our earth have been proposed, and some stoutly defended, only one has, until recent times, received universal recognition from astronomers, physicists, and geologists. This is the *Nebular Theory* of the earth's origin, first proposed in 1755 by Emanuel Kant, professor of mathematics and physical geography in Königsberg University, and independently developed in 1796 by Laplace in France, and amplified and modified by him in 1824. At present, a totally different hypothesis, the *Planetesimal Theory*, threatens to replace it, and has already been accepted as a more rational explanation of the origin of the earth by the majority of geologists and not a few astronomers and physicists as well. We may briefly contrast these two theories.

Essentials of the Nebular Hypothesis. — This hypothesis assumes that the substance of which the sun, the earth, and the other planets of our solar system are composed was originally diffused in space over an area extending beyond the orbit of the outermost planet (Neptune) of our solar system, or over a radius of more than 2,800,000,000 miles from the sun. This material was, of course, in a state of immense attenuation, constituting *a nebula* or luminous cloud of vapory matter, of the type now found in the heavens, and of which that of Andromeda, visible only on the clearest nights, has a diameter hundreds of thousands of times greater than the distance from the earth to the sun. Only one other nebula, that of Orion, is visible to the unaided eye, but the telescope shows the presence of more than a hundred thousand of them, and that is regarded by astronomers as only a fraction of those actually existing at the present time.

The nebula from which it was assumed that our solar system had been derived was thought to have been in a highly heated state, and to have revolved around the central nucleus, the present sun, assuming a disk-like form. Condensation, in the course of time, brought about the separation of a series of rings analogous to the rings of Saturn (Fig. 975), and these, rupturing and each condensing about a nucleus, would, in turn, form the planets. These planets, at first themselves large masses of attenuated substance, gave off equatorial rings, which, in turn, ruptured and segregated to form the satellites of the planets, this being the origin of our moon. In one case, however, the rupturing of the ring gave rise not to a single large planet, but to a vast number of minor planets or planetoids which revolve around the sun as a unit, forming the *asteroids* of our solar system.

The earth, according to this hypothesis, was thus at first in a gaseous state, from which, by condensation, a liquid and finally

FIG. 975. — The planet Saturn and its rings.

a solid state was produced, at which point the geological history commences. At first, all the water now upon the earth was held in a state of vapor in the atmosphere, which was then dense and hot and contained, moreover, many of the gases which have since united with other elements in the formation of rocks. Cooling gradually, many of the gases and the water were finally separated out of the atmosphere, and the oceans came into existence. These at first may have been very shallow and more or less universally distributed over the earth, but they became concentrated into separate basins as the crust of the earth began to assume definite form. The original crust resulted from the cooling and crystallization of the mineral material which at first was in a molten state, these original rocks being, therefore, of an igneous type.

At first a solid layer was formed over a still molten interior, but the breaking of this crust and the sinking of the fragments abstracted further heat from the interior, and eventually the earth became a solid mass, the interior of which is, however, still highly heated. The moon, according to this hypothesis, is regarded as a dead body, having cooled completely, as a result of which all the water, and the atmosphere as well, have been drawn into the body of the moon, leaving the surface without either, and hence incapable of supporting life.

Numerous objections have been advanced to this theory, especially in modern times, but for an understanding of these objections the student must have a knowledge of the mechanics of celestial bodies and of the molecular activities of gases.

Planetesimal Hypothesis. — The great majority of nebulæ in the heavens to-day are of a spiral type, with two dominant arms that arise from diametrically opposite sides of the nucleus and curve concentrically away (Fig. 976). Often there are more than two arms. In the outer part, and throughout the mass, but more especially on the arms, are knots of nebulous matter which represent greater condensation. It is around these knots as nuclei that further concentration takes place, according to this theory of planetary origin, but this concentration takes place by collision of numerous small particles, the *planetesimals* or little planets, of which the nebula is composed. By their gravitative force the nuclei would be able to retain the matter colliding with them and so become built up into planets, each clearing a zone around it of the planetesimals by ingathering, as it were. Thus the planet grows by accretion of solid material from without.

While the earth was still small, it was unable to hold the water vapor and other gases, which passed off into space. But with increasing size its attractive force became sufficient to retain at first the heavier gases, such as water vapor and carbon dioxide, and later the gases which form its atmosphere. The moon, according to this hypothesis, was never a part of the earth, but originated from a separate nucleus with essentially its present position with reference to the earth. The moon nucleus, being much smaller, attracted less matter and so never reached the size of the earth. All gases and vapors expelled as the result of the ingathering of the planetesimals became diffused in space because, on account of its small size, the moon was unable to when the first record of abundant and diversified life was made. The earliest Cambrian rocks are highly fossiliferous, abounding in organic remains which are, with few exceptions, the visible record of the most primitive life known to us. The rocks below the Cambrian, that is, the pre-Cambrian strata, are almost or wholly devoid of fossils. This does not mean that life did not exist in pre-Cambrian time — indeed, we know that it did — but only that few or no traces of it have been preserved in the rocks. Not only is there this abrupt expansion in the life record, but also a decided lithological break, emphasized usually by a structural unconformity which indicates that profound changes in the face of the earth took place before the deposition of the oldest Palæozoic strata. From the beginning of the Cambrian to the present we may measure time by the progress of life, and we may divide it into periods of relative lengths and may even attempt to express their duration in terms of millions of years. We have, however, few criteria for measuring time before the Cambrian, and there is even great difficulty in correlating the pre-Cambrian rocks without the aid of fossils. Nevertheless, from certain lines of evidence, it seems that the length of time preceding the opening of the Palæozoic was as great as, if not greater than, all the time which has elapsed since then. Considering these various facts, it seems most logical and convenient to reckon geological time from the base of the Palæozoic, taking that as the great datum plane from which to work upward and downward in the rocks, and forward and backwards in chronological events.

Character of the Basal Palæozoic Contact

The base of the Palæozoic, from which the student of the older rocks must proceed downward, is preceded, in nearly all cases where it is known, by a pronounced unconformity (more rarely a disconformity), in the majority of sections the underlying rock having a smooth, well-eroded surface, approaching sometimes a perfect plane. Moreover, these older rocks are generally highly metamorphosed, and as the overlying Palæozoic beds have not suffered such metamorphism, it is apparent that the former were metamorphosed and then subjected to prolonged erosion before the Palæozoic sediments were deposited upon that erosion surface. If the older rocks had been metamorphosed as the result of deep burial by Palæozoic sediments, we could not expect such a

Fig. 977. — Contact between pre-Cambrian and Potsdam sandstone, south of Hammond, St. Lawrence County, New York. (By courtesy of New York State Museum, John M. Clarke, Director.)

Fig. 978. — Detail of contact of nearly horizontal Potsdam sandstone upon somewhat contorted layers of Grenville quartzite, dipping from 20° to 36°, looking west. Taken at a distance of 4 feet, the notebook on the contact. One mile southeast of Redwood, Jefferson Co., New York. (H. N. Eaton, photo, 1908. Courtesy New York State Museum, John M. Clarke, Director.)

sharp line of contact at the base; and moreover, the lower portion of the Palæozoic rocks should show metamorphism in decreasing intensity upward.

Typical Sections Showing Contact. — The following sections may serve as illustrations of the contact between the basal Palæozoic and the underlying basement rocks. In the Adirondacks, a more or less pure quartz-sandstone, the Potsdam, lies directly upon the old gneisses, etc., the line of contact being sharp, and often with basal pebble beds in the sandstone immediately overlying. The age of the Potsdam sandstone is uppermost Cambrian, grading upward into

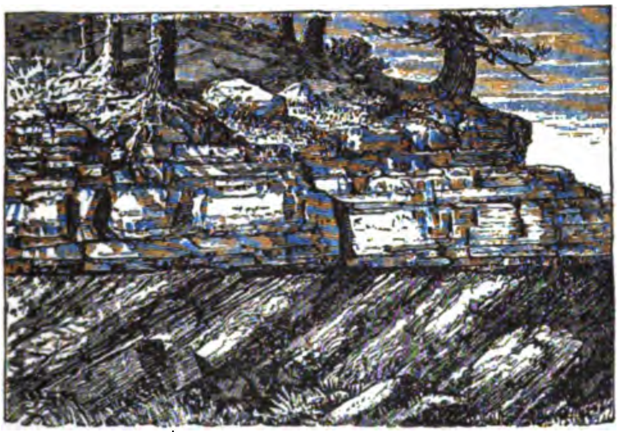


FIG. 979. — Upper Cambrian or basal Ordovician limestone resting unconformably on gneiss. Williams Cañon, Colorado.

a dolomitic limestone (Figs. 977, 978). In Canada, north of Lake Ontario, another basal quartz-sandstone rests upon the crystallines, with a smooth, sharp contact. It is followed by Middle or early Upper Ordovician limestones (Trenton, etc.). On the flanks of Pikes Peak in Colorado, a pure quartz-sandstone rests directly and sharply upon the granite, with an erosion surface on the latter of remarkable smoothness and very little variation (Fig. 979). This sandstone grades upward into fossiliferous limestones of latest Cambrian and earliest Ordovician age. A similar contact is shown in the Black Hills (Fig. 980). In the Ozark Mountains of Missouri, a fossiliferous quartz-sandstone of late Middle, or early Upper, Cambrian age rests upon the old erosion surface. It is also succeeded upwards by limestones. In central Texas, C brian sandstone rests unconformably on older rock (Fig. 981). On the shores of Lake Superior in northern Michigan, the basal contact between the early Palæozoic sandstone and the crystallines is diversified by the presence of numerous large, well-rounded boulders which rest upon the eroded surface of the crystalline rock and were evidently broken from a neighboring cliff in pre-Palæozoic time (Fig. 982). Similar conditions are seen in Wisconsin (Figs. 983, 984). Near Franklin Furnace, New Jersey, a fossiliferous quartz-sandstone of Lower Cambrian age rests directly upon the eroded surface of the gneiss and is conformably succeeded upward by a great limestone series. In southern Sweden, a basal sandstone of pure quartz, often with wind-carved pebbles (*Dreikanter*), rests upon a slightly weathered granite surface which is smooth and continuous. It is succeeded upward by fossiliferous limestones or shales.

FIG. 980. — Section on Lower French Creek, Black Hills, South Dakota. Archæan rocks unconformably overlain by Upper Cambrian. (After Newton.)

These are a few of many examples that illustrate the general character of the contact between the basal Palæozoic and the older rocks. It will be observed that the age of the basal sandstone is not always the same. In some sections it is Lower Cambrian, in others Middle, and in still others Upper Cambrian, while finally in

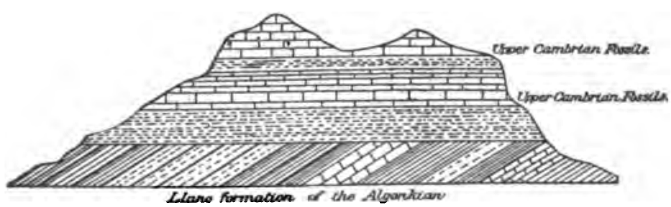


FIG. 981. — Section of Packsaddle Mountain, Texas. Showing inclined Algonkian beds unconformably overlain by Upper Cambrian. (After Walcott.)

some sections, — as in Canada, — it is of Ordovician age. This indicates overlapping of formations deposited by a transgressing sea (p. 556, Pt. I), but the overlapping is not thereby shown to be a continuous one. This will be more fully noted later.

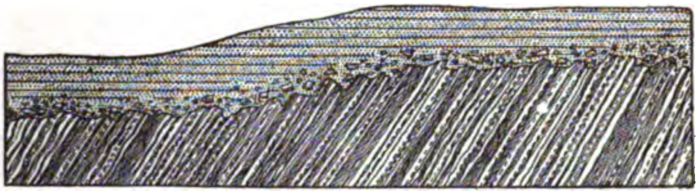


FIG. 982. — Section near Norway, Michigan, showing Potsdam sandstone, lying unconformably on ferruginous schist and ores of the Huronian iron-bearing series. (After Irving.)

FIG. 983. — Contact of Huronian quartzite and Potsdam sandstone. Baraboo River, near Ableman, Wisconsin. Scale 50 feet = 1 inch. (After Irving.)

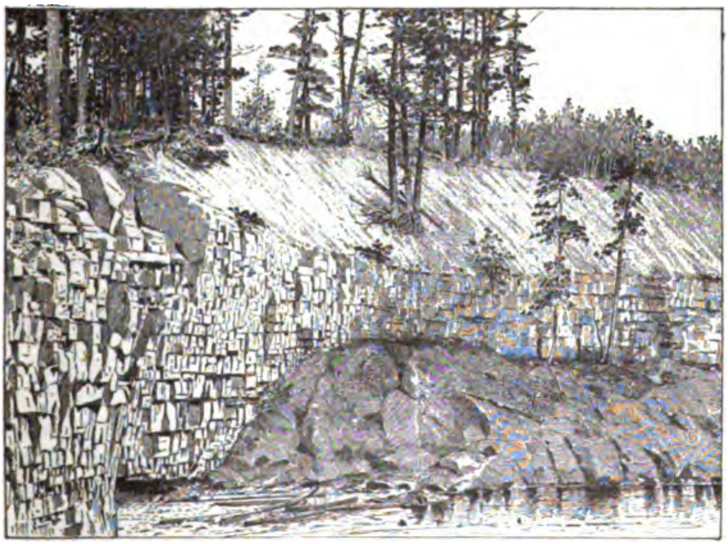


FIG. 984. — Unconformity between Potsdam sandstone and Archæan granite. Granite Point, Wisconsin. (After Walcott.)

Palæogeographic Significance of the Basal Contact and of the Character of the Early Palæozoic Formations Including the Basal Sandstone

In the study of the contact, it is to be noted that in North America, at least, the basal sandstone is generally followed by limestones, the two, as a rule, intergrading. If the quartz of the sandstone was the product of the disintegration and erosion of the crystalline rocks, as it undoubtedly was, we may ask what has become of the clay and other material which was the product of decomposition of the feldspars, etc., and which should have been produced in bulk equal to or greater than the quartz in the decomposition of the crystallines. It is evident that if the old land surface were covered with the product of atmospheric decay of the crystalline rocks, the sea, creeping up over it, would assort this material, separating the sand as a shore-deposit and carrying the clay out to deeper water. A moment's reflection will show that in such a case, a bed of clay-shale should follow the basal sands, at least in many localities, and yet this is not found, limestones always succeeding the sandstones.

This can only mean that the advancing Palæozoic sea found the surface of the oldland covered only by quartz-sand and that, moreover, this surface had already been eroded to the extent now seen, for if the Palæozoic sea had performed any part of this erosion, the product, including the clay, should be found among the deposits, but this is not the case, at least over an area extending from the Adirondacks to the Rocky Mountains, and from Canada south to Oklahoma and Texas. But as the evidence of erosion of the old rock is clear, and as the quartz of the basal sand could have been derived from no other source, we must conclude that before the advance of the Cambrian sea over much of North America, the products of disintegration had been thoroughly reworked by rivers and by wind, and the fine material (clay, etc.) removed to a distant region. This would imply a very long time interval, which is represented by the unconformity, and an immeasurable period of exposure of the pre-Palæozoic land surface to the atmospheric agencies of destruction. While this is the usual relationship of the Palæozoic and pre-Palæozoic rocks over the area described, there are certain sections where other series of rocks lie between the recognized basal Palæozoic and the oldest crystallines. These will be briefly noted in the succeeding paragraphs.

Typical Exposures of the Pre-Cambrian Rocks

The Western Rocky Mountain Region

The Uinta Quartzite Series. — While the basal Palæozoic sandstones (Upper Cambrian) rest directly upon the old crystalline rocks in the Rocky Mountain Front Range, west of this, especially in Utah, a great series of sandstones with some conglomerates and shales underlies the lowest recognized fossiliferous Cambrian bed, and in some localities is seen to rest in turn, with a pronounced unconformity, upon the older crystalline rocks. In a general way the material is coarsest and thickest in the eastern exposures, reaching 14,000 feet or more in some localities. It thins westward, at the same time becoming finer, while there are many variations due to irregularities of the old surface on which it was deposited. The series contains no fossils, this fact and the thickness and general character suggesting that it is a continental, probably river-laid, formation. It constitutes at present the core of the Uinta Mountains, and it is shown in parts of the Wasatch Range as well. It would seem that the rivers which brought this material came from the east, from a high land in the region of the present Front Range of the Rockies, and that they spread the sands in the form of a continental deposit or series of alluvial fans over an area which may have been slowly subsiding.

Following upon this in a disconformable manner is the basal Cambrian series, which is probably not older at any point than Middle Cambrian. This indicates that the old alluvial plain, if such it is, was deposited before the sea advanced over this area in Middle Cambrian time, but whether this deposit was formed during the Lower Cambrian or still earlier is not so clear. It probably belongs, in part at least, to the great period during which the continent farther east was undergoing erosion and assorting of the products of rock decay.

The Belt Terrane. — A similar series occurs in northwestern Montana, western Idaho, and southeastern British Columbia; its total thickness aggregates some 37,000 feet. Because of its fine exposure in the Little Belt Mountains, this series has been called the *Belt Terrane*. Clay and other mud-rocks predominate in it, and here we may perhaps recognize some of the clay which was removed from the eastern region during the period of exposure, as noted above.

In some layers of this rock are found the remains of a merostome of the *Eurypterus* type (*Beltina danai*, Fig. 985*a*), which is believed to be indicative of river deposition. In the eastern exposures, the Belt Terrane contains considerable red rock, suggestive of semi-arid conditions. Moreover, these rocks abound in mud-cracks, ripple-marks, worm burrows (Fig. 985 *b*) and other structures indicative of shallow water or playa conditions. Farther west, however, great limestone masses appear, crowded with spherical structures, apparently calcareous algæ of large size (Figs. 986, 987). These grew either in great fresh-water lakes or in lakes of intense salinity, like the Great Salt Lake of to-day. There appears to be no positive indication of the presence of the sea in this region at that time. Still farther west, sands apparently derived from the west replace the limestones, while disconformably overlying these deposits are rocks of Middle Cambrian age.

FIG. 985 *a*. — *Beltina danai* Walcott. (×2.) An appendage with two large basal joints and two smaller terminal joints. Greyson shale, Montana. (After Walcott.)

FIG. 985 *b*. — *Planolites corrugatus* Walcott. (Natural size.) Exterior cast of a burrow made by medium sized annelid in silicious mud now forming the shales carrying *Beltina danai* Walcott. (Greyson shales, near Neihart, Montana.) (After Walcott.)

FIG. 986. — *Newlandia concentrica* Walcott. A fossil nullipore or calcareous alga from the Algonkian (Newland limestone), Montana. (After Walcott.)

It must, of course, be understood that in some regions these rocks were violently disturbed by foldings and faultings after their formation, and that it is only by drawing a series of columnar sections at different localities, and arranging them in geographic order, that the condition and character of the rocks before the disturbance can be determined. Then it appears that this region was a part of a northwestwardly-extending geosyncline in which these deposits were formed. The formation of the red beds in the

FIG. 987. — *Collenia undosa* Walcott. A section of a sub-spherical specimen showing original growth as a dome and then a second growth that apparently occurred after the specimen had rolled over. (After Walcott.) Algonkian (Spokane shale), Montana.

eastern part of the series, while standing waters, either salt or fresh, existed in the central part of the geosyncline, suggests that this region was under the influence of easterly winds which left their moisture on the eastern slopes of the mountains that bordered the geosyncline on the east. It was in this same geosyncline that the alluvial fan deposits of Utah, which have been noted above, were formed.

Grand Cañon Series. — Farther south in this same geosynclinal belt, we meet with still another series of deposits of this type in northern Arizona, where it is well exposed in the walls of the Grand

Cañon of the Colorado. Resting unconformably upon the older crystallines is a series of red sandstones and dolomites with basaltic layers both at the base and at the top. This is the *Unkar* formation, and it is followed by the *Chuar* series, which begins with sandy shales interbedded with thin calcareous layers (about 3500 feet), followed by limestones and shales which pass upwards into reddish brown sandstones (about 1500 feet). The entire series has been slightly tilted and again eroded, so that the basal Palæozoic beds which are here of Upper Cambrian age (*Tonto sandstone*) rest unconformably upon the truncated edges of this series or upon the

FIG. 988. — Part of Grand Cañon section showing unconformable contact of Grand Cañon series (G C) on pre-Cambrian and the unconformable superposition of the Tonto sandstone on both. (After Walcott.)

older beds below (Fig. 988). In spite of the extensive erosion to which this series was subjected before the advent of the Upper Cambrian sea, there still remain some 12,000 feet of strata.

The Lake Superior and Other Canadian Regions

The Algonkian. — A second district in which the pre-Cambrian rocks have been extensively studied includes the regions south of Lake Superior and north of Lake Huron. On the Keweenaw Peninsula of Michigan and the adjoining region, the Upper Cambrian sandstones are preceded by a great series of conglomerates, coarse, red and white sandstones with interbedded conglomerates, and shale with some thin beds of limestone. This is known as the *Keweenawan* series. The sandstones are often feldspathic, indicating relatively dry climate, as do also the red color of the shales and the mud-cracks abounding in them. With these sediments occur vast sheets of basic lavas (basalts, melaphyres, etc.), but also some rhyolitic rocks. Some of the conglomerates are derived from these contemporaneous igneous rocks. These lavas carry the silver ore and native copper which have made the region of such great economic importance. Lavas of the same age are also believed to be responsible for the great nickel and copper deposits of Sudbury, Ontario, and the silver of the Cobalt region, where the lava forms a great diabase sill or intruded sheet in the older Cobalt conglomerates. Cobalt, gold, platinum, etc., were also brought by this lava or the attendant gases and vapors into this portion of the earth's crust.

Below the Keweenawan lies a still older series of sediments which is now found in a number of isolated areas scattered over the Canadian shield and extending far into the Arctic regions. This is called the *Animiki* series, and it is of special economic significance because it carries everywhere great deposits of iron ore, which in places may reach a thickness of 1000 feet.

The Animikian strata are still for the most part horizontal, and in the various erosion remnants the thickness which remains after prolonged denudation varies from 6000 feet to 14,000 feet, the latter in the Penokee area of Michigan. The remnants now found were either masses locally faulted down after deposition or deposited in gently warped basins. The former extent of the formation was undoubtedly over a much greater area, especially if, as many hold, the beds were of marine origin.

The formation often begins with a basal conglomerate, the pebbles of which were derived from the older gneisses and schists. This is succeeded by chert and jasper, banded or oölitic, or by beds of impure cherty limestone or dolomite. Still higher are many beds of thinly laminated carbonaceous shales, carrying from 6 to 10 per cent of carbon, which, if concentrated from all the beds, would make a layer of anthracite about 200 feet thick. Beds of sandstone also occur, and in some sections the strata are intruded by sills and dikes of the later Keweenawan lavas.

No undoubted marine fossils have been found in these strata, and their reference to a marine origin is based upon their general character and appearance. They may have been formed in an extensive series of fresh-water or saline lakes, into which rivers carried their sediment, and in which iron ores analogous to the bog ore of modern swamps were accumulating.

The presence of pebbles of the red jasper of the Animiki formation in the Keweenawan conglomerates indicates the younger age of the latter formation.

Still another older series of rocks is found beneath the Animikian series, separated from it by an erosion interval. This is the *Huronian* series, the lowest of the Algonkian formations. It begins with a basal conglomerate which contains boulders up to two, three, or even five feet in diameter, and pebbles, the surfaces of which show distinct grooving and striation of the type known to us from the ground moraine which covers the rock nearly everywhere in the northeastern part of North America and northwest Europe. The material in which these boulders are embedded also resembles that of the more recent till, except, of course, that it is consolidated. The conclusion has been reached by students of these rocks that they represent an old till or subglacial deposit, now hardened into rock (tillite). This would imply that at the beginning of Algonkian time the Canadian region was subjected to glaciation, though the extent of this glaciation is not determined. The basal series of the Huronian is not all tillite, but interbedded with the glacial boulder conglomerates are thick zones of slate, quartzites, and conglomerates spread out by running water, thus indicating alternation of warmer periods with those of glaciation.

The thickness of the deposit usually does not exceed 500 or 600 feet, and it covers an area extending 1000 miles east and west and 200 miles northward from latitude 42° N. It rests upon a level erosion surface of the much disturbed older rocks which had been thoroughly peneplaned (Laurentian Peneplane) before the boulder conglomerate was deposited. The basal conglomerates are succeeded by quartzites (sometimes conglomerates), which may reach a thickness of 1000 feet, and overlying these in the Lake Huron region is a limestone about 300 feet thick which has been regarded as marine, though the fossil evidence is lacking. This limestone is succeeded by an immense series of clastic rocks beginning with arkoses (up to 2300 feet), followed by red jasper conglomerates (2150 feet), white quartzite (2970 feet), chert with limestone and slate (400 feet), and white quartzite (1500 feet). This series of nearly 10,000 feet of clastics appears to be of continental origin and probably represents river flood-plain and alluvial fan deposits, with possibly lake delta conditions similar to those of the Cooper River, Lake Eyre, in Australia (p. 467, Pt. I).

In the Rainy Lake region, north of Minnesota, the Huronian begins with an impure limestone 500 feet thick, which rests directly upon the Laurentian Peneplane surface, the tillite conglomerate being absent. In this limestone, fossils have been found at Steep Rock Lake, west of Port Arthur, Ontario. These, the oldest undoubted fossils (*Atikokania*) from the North American continent, are cylindrical, cornucopia-shaped, and semi-globose masses, ranging in diameter from one to fifteen inches. In structure they resemble the calcareous algæ found in the younger Algonkian limestones of the northwestern region, and it is highly probable that they are of similar nature. They have been regarded as indicating marine waters, but this is not necessarily the case, and is rather strongly negatived by the absence of normal marine organisms, though, of course, it is not certain that marine animals in Huronian time had hard parts capable of preservation. Still these algæ, if such they be, may have been formed in fresh water, as Walcott holds the algæ of the limestones in the Belt Terrane were formed, or they may have developed in circumscribed saline lakes. The age of this limestone is thought to be the same as that of the one which lies some distance above the tillite in the Lake Huron region.

The Archæan. — As we have seen, the Huronian tillites, or, in their absence, other Huronian deposits, rest upon the old peneplane which, on the whole, is very level or gently undulating. It is upon this ancient peneplane, more or less perfected by further erosion during Algonkian time, that the Cambrian and overlapping Ordovician strata rest wherever the Algonkian beds were not deposited or, having been deposited, were removed again by erosion before the Palæozoic strata were laid down. Over large areas in Canada the old peneplane is even now exposed, usually by the removal of the younger strata which once covered it. A certain amount of deformation has, however, occurred at various periods up to quite recent times, and the elevated portions have been strongly dissected. As a result, some parts of the old peneplane are now more or less deeply dissected mountainous uplands (See Fig. 990).

FIG. 989. — SIR WILLIAM LOGAN.

The Sudburian. — While the Algonkian rocks of the Canadian region are, on the whole, only slightly deformed, and often still nearly horizontal in position, those of the Archæan series beneath them are strongly folded and exhibit many igneous intrusions, the Laurentian Peneplane cutting across the folds. For the most part these older rocks are gneisses of various kinds, which were originally designated as the *Laurentian* gneisses by Sir William Logan (portrait, Fig. 989). Folded in with them, however, and preserved in a number of long, narrow belts, is a younger series of

FIG. 990. — Diagrammatic sections showing the development of the Laurentian peneplane.

a. This shows the oldest sediments, the *Coutchiching* (1) with the succeeding *Keewatin* lava flows (2) and the equivalent *Grenville* series of the eastern region (3). These have been strongly folded during the *Laurentian Revolution* and intruded by the basal granites (4); during the succeeding *Ep-Archæozoic* interval the old Laurentian mountains were planed down, and upon the peneplane thus produced the *Sudburian* series of delta deposits (5) were laid down. b. This shows the folding of the entire series during the *Algomian Revolution* with the development of gneissic structure in the old granites (4) and the second granitic intrusion (6) with the probable formation of volcanoes upon the surface. During the *Ep-Algomian* period of erosion these mountains were planed down to the level indicated by the horizontal line, producing the *Laurentian peneplane*. c. This shows the completed Laurentian peneplane, upon which the Huronian and later Algonkian sediments were deposited. (a, b, original, c modified after Barrell.)

sediments in synclinal folds which trend in a general northeasterly direction. These sediments are themselves unconformably related to the gneisses, and thus indicate a period of sedimentation between two periods of mountain folding which preceded the formation of the Laurentian Peneplane (Fig. 990). They constitute the *Sudburian* series of sediments, which has a total known thickness of 20,000 feet and apparently represents great alluvial or delta-like deposits over 15,000 feet thick, consisting chiefly of white cross-bedded quartzites with interbedded shales but no carbonaceous material. The lower 5000 feet often contain arkosic material, or cross-bedded impure sandstones or graywackes. Generally, too, there is a basal conglomerate. These basal beds are of more local origin than the great mass of the sands, which, like those of the Cooper River delta of to-day, were probably derived from a considerable distance. These rocks were strongly folded, with accompanying intrusions of granite, and the resulting Algomian Mountains, as they have been called, were worn down until the Laurentian Peneplane was produced.

But as we have seen, the Sudbury quartzites themselves rest unconformably upon an older series of rocks which constitute the basement complex so far as now known. Over large parts of the country this basement complex consists chiefly of altered granites or granite gneisses, and originally these were regarded as representing the oldest rocks of the earth's crust upon which the original sediments were laid down. These Laurentian granites, as they are called, have associated with them many kinds of ancient sediments usually much altered, and whereas it was originally believed that these sediments were deposited upon the old granite gneisses, close study has shown that the contact between them is not sedimentary but igneous; — that, in other words, the sediments are the older, and the granites are intruded into them, and therefore younger.

Coutchiching and Keewatin Series. — The oldest Archæan sediments have been especially studied in two regions in Canada, *i.e.*, the Rainy Lake district north of Minnesota and the area lying north of Lake Ontario and east of Lake Huron in the province of Ontario. In the former region these sediments are known as the *Coutchiching* series, and consist now of graphitic mica schists and dolomites, with a known thickness of about 4600 feet. These schists appear to have been originally beds of bituminous shale, such as abound in the Palæozoic and later formations. During metamorphism the carbonaceous content of these shales was changed to graphite scales. Overlying this series is a great mass of greenstones and green schists, the *Keewatin* series, with a thickness ranging from 6500 to 23,700 feet. These rocks represent ancient lava flows, mostly basalts, which were poured out over the Coutchiching series, and beds of volcanic ash, all of which have undergone much alteration during metamorphism. The upper part of this series, for perhaps 1500 feet, consists of interbedded banded jasper and iron ore, the latter now altered to hematite and magnetite, and it also contains limestones, the entire series often resting on carbonaceous slates.

Grenville Series. — The Archæan sediments of Ontario are known as the *Grenville* series, and they are believed to be the essential

FIG. 991. — *Eozöon canadense*, Archæan, St. Pierre, Canada. (From Haug, *Traité de Géologie.*)

equivalent of the formations just described. The Grenville series contains much calcareous matter in the form of crystalline, pinkish limestones or coarse-grained marbles and dolomites. In one section a total thickness of over 94,000 feet of strata has been determined, more than half of it being calcareous. The beds of crystalline limestones alternate with quartzites which are altered sandstones, and there are interbedded hornblende schists and gneisses formed from alteration partly of igneous intrusives and partly from the original sediments in contact with the intrusives. Some of the beds are graphitic, representing altered carbonaceous rocks. Basaltic lava flows also occur at the base of the Grenville series.

The ancient Archæan sediments of the Canadian region were strongly folded after their formation, while extensive intrusions of granite took place, greatly altering them. This was the first known period of disturbance and of granitic intrusions, and it was followed by a prolonged interval of erosion before the Sudbury sediments were deposited. Rocks of the age of the Grenville series also occur in the Adirondacks, in the Highlands of the Hudson and their continuation into New Jersey, and in the northern Appalachian region. In the Adirondacks, graphitic and other crystalline limestones also occur, together with heavy beds of graphite schist, which appear to have been originally bituminous shales. The amount of graphite varies from three to ten per cent by weight of the rock, some beds of the graphite schist being so rich and so thick as to have the appearance of coal seams. In the Highlands of the Hudson and New Jersey, gneisses predominate, but locally limestones also occur.

Fig. 992. — Sir J. W. Dawson.

Fossils of the Grenville Series.—While the presence of the graphite suggests strongly the occurrence of plants and perhaps animals during the period of deposition of the Grenville series, it can be regarded only as indirect proof of such an existence. The same thing may be said of the occurrence of the limestone and iron ores, for while such deposits in later periods often indicate the physiological activities of organisms, it cannot be denied that these older limestones and iron ores may have been of purely chemical origin. More direct evidence of life is furnished by what has been regarded by many as true fossils in the Grenville limestone, though others have denied their organic origin. These are globular or irregular masses of lime and serpentine material, sometimes with a diameter of several feet, the calcite layers alternating in regular succession with the serpentines and interpenetrated by them in such a way as to suggest a complicated series of canals and tubes (Fig. 991). At first these masses were thought to have been built by Protozoa, the calcite representing the shelly material deposited over and around the organic matter the place of which is now taken by the serpentine. On this account the supposed organism was named by Sir William Dawson (portrait, Fig. 992), its discoverer, *Eozoön canadense*, or the Canadian dawn-animal. At present the tendency on the part of palæontologists is to consider these masses as more probably of algous origin, *i.e.*, a form of lime secreted by lowly plants, either marine or fresh water. There are, however, many geologists who regard these masses as the product of crystallization during metamorphism.

Summary of the Pre-Cambrian of the Canadian Region

We may summarize the succession of known pre-Cambrian events in the Canadian region in the following table:

13. Interval of erosion, preceded by moderate disturbance of the strata, and succeeded by Palæozoic sedimentation.
12. Deposition of the Keweenawan series of alluvial and delta-like deposits, and outpourings of Keweenawan ore-bearing lavas and their intrusion into some of the older sediments.
11. Interval of erosion, preceded by slight disturbances.
10. Deposition of the Animiki iron-bearing series of cherts, jaspers, oölites, limestones, and carbonaceous shales.
9. Interval of erosion preceded by elevation and warping of the land.
8. Deposition of Huronian strata.
   - 8*c*. Upper arkoses, jasper conglomerates, and quartzites.
   - 8*b*. Middle limestones, with basal sandstones and carrying calcareous algæ in some places, and sometimes overlapping the lower tillites.
   - 8*a*. Lower tillites apparently of glacial origin.
7. Great period of erosion and formation of Laurentian Peneplane.
6. Second folding and metamorphism of the older formations and second intrusion of Laurentian granites.
5. Deposition of the Sudbury series of continental quartz sands.
4. Great period of erosion.
3. First period of folding, mountain-making and metamorphism of the older rocks and first intrusion of Laurentian granite.
2. Deposition of the Archæan sediments.
   In western region:
   - 2*b*. Upper or Keewatin series of volcanics, of pyroclastics and other sediments.
   - 2*a*. Lower or Coutchiching sediments.

In eastern region:

2a and b. Deposition of Grenville series of limestones and clastic sediments with some volcanics.

1. Formation of the earlier unknown rocks of the earth's crust from which the oldest clastics were derived and upon which they were deposited.

Other Pre-Cambrian Sediments of North America

Pre-Cambrian sediments have been found in several other localities in North America, but they have not yet been studied

Fig. 993. — General view of the Avalon series, Cape Bonavista, Newfoundland.

to the same extent as those described above. On the Avalon Peninsula of eastern Newfoundland there is found an extensive series of folded quartzites, slates, and other rocks only slightly metamorphosed, and carrying, in some cases, indistinct organic remains (Fig. 993). This *Avalon* series, as it is called, was truncated by erosion after the folding, following which marine sediments of Lower Cambrian age were deposited over it. Another series of inclined more or less metamorphosed pre-Cambrian strata is known from central Texas, where the eroded and truncated ends are overlain by late Cambrian marine sediments. (See Fig. 981,

p. 184.) Both of these series are referred to the Algonkian, but their exact correlation with the Canadian succession is not yet possible. The outcrops of the pre-Cambrian formations of all kinds are shown on the accompanying map (Fig. 994), but it must

FIG. 994. — Map of North America in pre-Cambrian time. (After Van Hise and Leith.) *C. S.*, California Sea, arrows indicate probable path of advance of ocean over continent. Diagonally shaded areas, Algonkian, including Keewatin areas in Canada and the Lake Superior region. Horizontally shaded areas, ancient schists and intrusives (generally pre-Cambrian but including Palæozoic and possibly younger metamorphic rocks and intrusives. In Canada, the Laurentian in general.)

be remembered that everywhere they underlie the younger rocks — that, in other words, the whole of the North American continent is formed of pre-Cambrian rocks, portions of which are covered by sediments of Palæozoic and younger age.

Pre-Cambrian of Scotland

An instructive series of pre-Cambrian rocks occurs in the Highlands of northwest Scotland. Here the basement rock is the *Lewisian gneiss* (Fundamental gneiss), regarded as the product of the metamorphism of plutonic rocks. Schists also occur with the series, and these are interpreted as the alteration products of ancient sediments. The whole is intruded by basic as well as acid igneous masses in the form of dikes and sills.

Part of this fundamental complex shows a pronounced erosion topography which was carved in Algonkian time, with hills rising in places 2000 feet or more. The climate in later Algonkian time seems to have been of a semi-arid character, for disintegration of the granite gneisses occurred with but little decomposition of the feldspars. As a result, a great mass of arkosic material was produced, which accumulated in the valleys to a depth of perhaps 14,000 feet. In many cases the orthoclase crystals of this arkose are so fresh and large that the rock appears superficially like a coarse granite. This is the *Torridon Sandstone* which, on the whole, has been little disturbed, and is still largely unmetamorphosed. Along the flanks of the old mountains from which the material was derived, and generally at the base of the formation, it is commonly coarse and bouldery, grading away into arkose sandstones of finer grain. Cross-bedding is frequent, and some of this appears certainly to be of eolian character. As further evidence of pronounced wind-work in Torridon time, may be mentioned faceted boulders or pebbles of the *dreikanter* type which are occasionally found in the deposit. The prevailing color of the formation is red, but there are also gray micaceous shales and sandstones, and occasionally some thin calcareous layers. These are sometimes marked by what appear to be trails of organisms, but other fossils have not been found. On the whole, this seems to be a continental deposit of the intermontane type, formed by torrents, and modified by wind during a period of relative aridity. Subsequent erosion has in places removed this sandstone and reëxposed the old pre-Torridonian hills and valleys, part of the latter being occupied by modern streams.

Slight warping and deformation of the Torridon beds occurred, followed by prolonged erosion which left only remnants of the once widespread formation. Then the erosion surface was submerged beneath the encroaching Cambrian sea, Lower Cambrian sandstones, shales, and limestones being deposited in places upon the eroded edges of the Torridon Sandstone or, where this had

FIG. 995. — View of Craig Roy on Loch Maree, Scotland. The nearly horizontal rocks in the greater part of the craig are Torridon sandstone (pre-Cambrian). Above these, with a gentle unconformity, lie the Lower Cambrian beds with *Olenellus*, etc.

been removed by erosion, upon the old gneiss direct (Fig. 995). More recently still, great crustal movements occurred, which caused the gneiss locally to override the older Palæozoic sediments (Fig. 996). In the main mass of the Highlands these thrusting move-

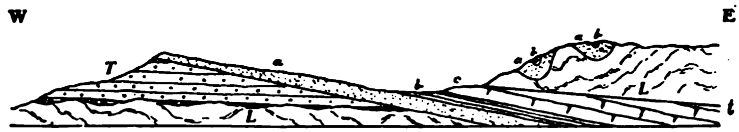


FIG. 996. — Diagrammatic section across the northwest Highlands of Scotland. *L*, Lewisian gneiss; *T*, Torridon sandstone; *a*, Arenaceous series of Cambrian; *b*, Middle series; *c*, Calcareous series; *t*, Thrust-plane. Note: The overthrusting is much more complex than is shown in this diagram. (From Lake and Rastall, *Textbook of Geology*.) (See also Fig. 550, p. 629, Pt. I.)

ments were accompanied by intense metamorphism which altered the rocks to such an extent that their separation into Palæozoic, Torridonian, and Lewisian has not yet been accomplished.

The Pre-Cambrian Rocks of Finland, etc.

The best known development of the older rocks of Europe is found in Finland, where the series has a thickness of many kilometers. There, as elsewhere, the highest division is little altered, and for the most part still undisturbed. The succession is as follows, in descending order.

CAMBRIAN SANDSTONES and shales mostly absent.
Erosion interval. (No folding).
ALGONKIAN SERIES.
Jotnian formation. Quartzites and ripple-marked sandstones, conglomerates and clay slates with intrusive diabases and "Rapakiwi" granite not folded and but slightly altered, thickness up to 2000 meters.
Erosion interval preceded by more or less folding of older series.
Jatulian series. Clay-shales and bituminous shales with a bed of anthracite coal 2 meters thick, besides dolomites, quartzites, and conglomerates. Some of the strata characterized by ripple-marks and mud-cracks. Intrusive and effusive diabases. Also gabbro intrusions. Folded, but little altered, and sometimes nearly horizontal. Thickness, still nearly 1500 to 2000 meters.
Erosion interval, preceded by folding of older strata.
Kalevian series. A metamorphic series of schists, cross-bedded quartzites, coarse conglomerates, and dolomitic limestones. All strongly folded.
Great-erosion interval preceded by folding of older strata.
ARCHÆAN SERIES.
Bottnian series, metamorphosed schists, quartzites, conglomerates, tuffs, and porphyries.
Erosion interval preceded by folding.
Ladogian series. A metamorphic series of phyllites, mica schists, quartzites, conglomerates, crystalline limestones, etc., resting upon (or intruded by)
Fundamental granite-gneiss.

The prevailing strike of the Archæan foldings is southwest and northeast, that of the older Algonkian northwest, or prac-

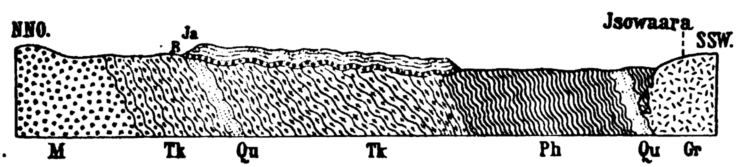


FIG. 997. — Section of the pre-Cambrian rocks of Lapland. *M*, Kalevian series (metamorphosed greenstones); *Tk*, Kalevian talc chlorite schist; *Qu*, Kalevian-quartzite; *Ph*, Kalevian phyllite; *Gr*, Post-Kalevian intruded granite; upon these highly inclined beds rest the gently folded Jatulian basal conglomerate (*B*) and quartzite (*Ja*). (After Sederholm, from Kayser.)

tically at right angles to the older series. A section of the older rocks of Lapland is given in figure 997.

Pre-Cambrian Glaciation

We have seen that there are indications of the existence of glaciers in Huronian time in parts of Canada, for the base of the Huronian series contains an old tillite, or consolidated glacial till, with scratched boulders and pebbles. In other portions of the world the fossilifer-

Fig. 998. — Contact of Algonkian (€ng), and Cambro-Ordovician beds (€oks), with layer of old glacial till 120 feet thick between (€nt). Yangtze River, Province of Shensi, China. (After Willis, from Walcott.)

ous Cambrian beds are preceded by similar tillites, and some of these are so extensive and present such unmistakable characteristics, that they must be interpreted as the product of widespread continental glaciation at, or before the opening of, Palæozoic time.

The best known examples of such late pre-Cambrian or early Cambrian glaciation exist in the southern hemisphere, in Australia and South Africa, and one, apparently of equal extent and importance, is found in eastern China in latitude 31° N., where in the exposures of the Yangtze Cañon they are seen beneath the fossiliferous Cambrian beds, and include beautifully striated pebbles comparable in all respects to those found in the till of the Pleistocene glacial deposits. (Figs. 998, 999.)

In Cape Colony, South Africa, is found a tillite of the same age (*Griquatown* series), which has been traced over an area of 1000 square miles. This lies in general in latitude 29° S., and, like the Australian deposits, approaches the equator more closely than do any of the glacial deposits of the Pleistocene period.

FIG. 999. — Glacial striæ on boulders in a mudstone at the base of the Cambrian. Nan'tou on the Yangtse (China). (After Bailey Willis.)

In South Australia, such tillites are now found to form a part of the Mount Lofty Ranges; and they have been traced over an area extending 460 miles, from the west coast of Tasmania on the south, to latitude 33° or 30° S. and for 250 miles from east to west (Fig. 1000). Intercalated in these tillites are beds of limestone which contain what appear to be radiolarian remains, while one contains Archæocyathid corals (see beyond). Because of this, it is argued that the glaciers which deposited these tillites reached the sea; in other words, that these deposits at the time of their formation were close to sea-level and indeed extended into the sea and that floating icebergs carried these boulders, while during intermittent warmer periods marine limestones were formed. This is a significant fact, for it would imply that at that early period the climate of South Australia was comparable to that of Alaska or Greenland, where glaciers descend into the sea to-day. If that were the case, we would have to assume either that the climate of the earth as a whole was much colder at that time, or that the arrangement of the climatic zones upon the earth's surface was different at that period, so that some of the warmer regions of the

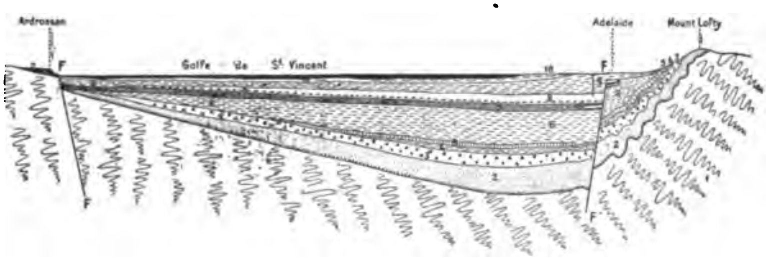


Fig. 1000. — Cross section showing the stratigraphic relations of the Cambrian glacial formations of Australia. (After Walther, Howchin.) 1, Crystallines; 2, quartzites; 3, mudstone with Lower Cambrian boulders; 4, shales of Tapley's Hill; 5, limestone of Brighton; 6, purple shales; 7, limestone with *Archæocyathus*; 8, Permian glacial beds; 9, 10, Tertiary; *FF*[1] faults.

present earth were arctic. This would imply that the poles of the earth were not in the position which they occupy to-day, but that both the north and the south pole had a different location. No other known explanation is adequate to account for such a difference in position of the climatic zones, if that actually obtained. If the poles of the earth were in their present position, and the climate of the whole earth were lowered sufficiently to permit glaciers to extend from the South Pole to South Australia and South Africa on the one hand, and from the North Pole to the Yangtze on the other, the present polar regions must have suffered extremes of refrigeration far beyond those known to-day. In that case the change in climate which followed this period of cold was a remarkable one, for both in the arctic and the antarctic regions of to-day deposits of Cambrian age suggestive of mild, if not of warm, climate were formed.

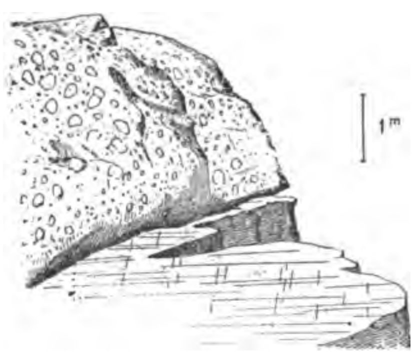


Fig. 1001. — Polished and striated sandstone underlying a thick moraine at the base of the Cambrian. Bigganjarga, near Karlbotn, Varanger fjord, Norway. (After Hans Reusch.)

Evidence of ancient glaciation is also found in the extreme north of Europe, where at Varanger fjord on the north coast of Norway, the pre-Cambrian rocks are beautifully striated and polished, comparable in all respects to the glaciated surfaces of rocks under the Pleistocene till. These polished surfaces are covered by a tillite full of striated boulders, and this in turn is succeeded by a bedded rock without fossils and of uncertain age (Fig. 1001). It has been thought that the glacial period here indicated belonged to the early Cambrian or pre-Cambrian, but the evidence for this is entirely inconclusive. So far as the age of the overlying rocks is concerned, this may be Devonian or even Triassic if not younger, and therefore it is quite possible that the glaciers responsible for these phenomena existed in this region in post-Palæozoic time.

Pre-Cambrian rocks are exposed in many other regions of Europe and over wide areas in Asia, but they have not been studied in the same detail.

CHAPTER XXXI

GENERAL CHARACTERS OF THE PALÆOZOIC

The Palæozoic history of the earth presents itself to us in two phases, physical and biological. From either aspect it appears as a unit, there being consecutive and orderly development both in physical geography and in life, neither being affected by any marked or violent interruption. Both at the beginning and at the end of the Palæozoic, however, the changes were pronounced, although, as has already been said, the organisms of the Palæozoic had their ancestry in those of pre-Palæozoic time and from them, in turn, were derived those of the Mesozoic. In either case, however, the change appears to have been a marked and comparatively rapid one, preceded at least at the end of the Palæozoic by widespread extinction of the dominant types.

Palæozoic Seas and Lands

We shall at the outset note briefly the general characteristics of the Palæozoic seas and lands. There is at present no reason for believing that the continents and ocean basins as a whole were different from what they are to-day, although it is certain that in form and minor characters they had their own peculiarities.

The Oceans. — There is little doubt that both the Atlantic and the Pacific oceans were in existence in Palæozoic time, though it is probable that they were, on the whole, much shallower than they are to-day. Furthermore, it is certain that the Atlantic Ocean was much smaller than at present, for land masses replaced part of its western and northeastern border regions, and for part of the time, at least, its northern border region as well. Our information regarding the Pacific of that era is less detailed, but it appears that its eastern border zone was for a time usurped by a land mass of unknown extent. The Arctic Ocean was also in existence during Palæozoic time, but we know from the organisms which inhabited it that the waters were of a much higher temperature than at present, being, indeed, locally at least, comparable to waters of the modern tropical seas. Whether this was due to a general higher condition of temperature of the earth's atmosphere and waters at that time, or whether it was due to a different arrangement of the zones of temperature in the Palæozoic, is a mooted question. Some have held that the temperature of the earth's atmosphere and waters was more nearly uniform at that time than it is to-day, — that, indeed, climatic zones did not then exist upon the earth. Aside, however, from the difficulty of conceiving of a planet like our earth with a definite relation to the sun as being deprived of climatic zones, — unless we assume that the earth was wrapped in a continuous mantle of clouds, — there are positive indications that climatic zones did exist even at this early time and that, while tropical conditions prevailed in some regions, Arctic conditions prevailed in others; but the distribution of these conditions over the surface of the earth appears not to have been the same as it is to-day.

It has been thought by some that this difference in distribution of climatic zones, if such obtained, might have been due to a different position of the earth upon its axis, or, in other words, to a difference in the position of the poles, while yet the general relation of the earth's axis of rotation remained the same with reference to the sun. Thus, it has been suggested that during the Palæozoic one pole might have been located in the region of the present Indian Ocean and the other somewhere in the Pacific, which would carry the equator of that time more nearly through the present polar regions. Serious objections have, however, been advanced against such a view, and we must leave this problem unsolved for the present. That climatic conditions in Palæozoic time differed in different parts of the earth (though not necessarily in all) from to-day is clearly indicated by the distribution of the Palæozoic organisms as well as by the characteristics of the deposits, as will appear more clearly presently.

We know very little regarding the extent and character of the Indian Ocean in Palæozoic time, but of its existence there seems to be little doubt, though extensive land masses may have reduced it much in size.

Epeiric Seas. — A characteristic feature of the Palæozoic was the extensive development of epeiric seas of the type now represented by Hudson Bay in North America and by the Baltic Sea in Europe. They were, for the most part, shallow and covered large areas of the present continents, at least in North America, Europe, and Asia. South America and Africa, on the other hand, seem to have been characterized in Palæozoic time merely by shallow marginal indentations from the sea, the greater part of these continents being above water, then as now. The same was true, though perhaps to a lesser degree, of Australia. The conditions of the Antarctic continent at that time are still unknown.

The several epeiric seas which covered the continents of the Palæozoic were extensions from one or the other of the great oceans of the time, and several such extensions, each from a separate ocean, may have occupied a continent at the same period. Unless these epeiric seas became confluent, their faunas remained more or less distinct, being derived in each case from the ocean of which the epeiric sea was an extension. For just as is the case to-day, each ocean had its peculiar fauna and flora, although there were certain types which were fairly well represented in two or more of the oceans. When the epeiric seas became confluent, a temporary commingling of the faunas occurred, and in some cases a wide distribution of certain organisms over the earth could take place. Such widely distributed organisms became then the most characteristic of index fossils of the contemporaneous deposits in widely distant regions of the earth.

When an epeiric sea, peopled with organisms from one of the oceanic sources of supply, became more or less effectively separated from that ocean, a slow differentiation of the organisms, thus isolated, took place, and after a time a new assemblage of marine animals, that is, a distinct fauna, came into existence, in the area thus restricted. With renewed opportunities for spreading widely, this fauna later often became more or less cosmopolitan. Thus, while in general the development of the organisms in the ocean basins was slow, more rapid evolution took place wherever a group was isolated and thus new faunas came into existence. Attention will be called to some of these in their proper places.

Geosynclines. — During Palæozoic time there were certain areas of more or less continuous subsidence, interrupted in some cases and terminated in all by foldings of the strata deposited in them. These areas, the *geosynclines*, were in general parallel to the principal land masses of each continent, from which they received a more or less constant supply of clastic material. Though on the whole subsiding continuously, the geosynclinal belts were not always submerged beneath the shallow epeiric extensions of the oceans, but frequently their surfaces stood above sea-level, at least in part, and the deposits formed in them were of continental character. Sometimes these geosynclines were confined between land-masses, but in other cases they passed, in the direction away from the principal land mass, into a shallow epeiric sea. Map Fig. 1002.

It is in these geosynclines that the thickest deposits of the Palæozoic were formed, those of the Appalachian Mountains, the

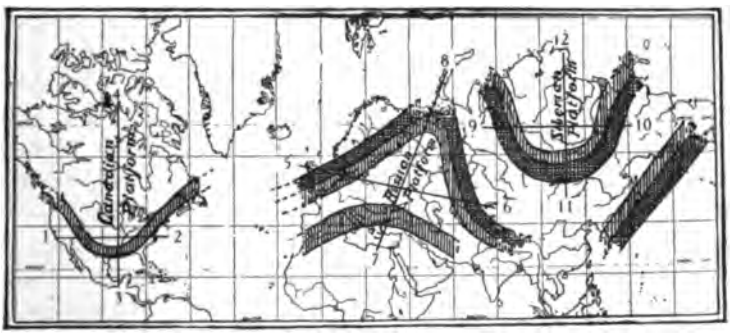


FIG. 1002. — Generalized map of the northern continents, showing the location of the more important geosynclines of Palæozoic time. The darker geosynclines are of later Palæozoic age, forming in the oldland after the folding of the sediments of the older Palæozoic geosynclines. The figures show the position of the sections in the succeeding diagrams (Figs. 1003–1005). (Original.)

type region of geosynclines, reaching a total thickness of over 40,000 feet. For the most part these geosynclines were long and comparatively narrow and they later became the sites of the principal mountain folds formed during and at the close of the Palæozoic.

The Land Masses. — In Palæozoic time certain dominant land masses, quite distinct from the dominant land areas of to-day, were in existence, and it was from them that the bulk of the clastic material which was deposited in the geosynclines and epeiric seas and upon the low lands was derived. As they were distinctive for each of the continents, these land masses will be more fully described in connection with the principal geographic conditions of each.

Palæozoic Land Masses of North America

Appalachia. — The most prominent of the land masses in eastern North America during the whole of Palæozoic time was *Appalachia*, which lay, in a general way, along the eastern border of the continent, extending eastward into the present Atlantic area for an unknown distance. There is good reason for the belief that this land mass extended continuously from Newfoundland on the north without interruption to the Brazilian oldland of South America and beyond, involving, indeed, the greater part of South America, of which it was the northward extension. (See Fig. 1186, p. 336.) Some palæogeographic maps show the land interrupted in the Gulf of Mexico region, so that the Atlantic waters are connected with the interior epeiric seas. There is, however, no good evidence for such an interruption, and indeed the known facts point to a continuous land mass. The cores of the West Indian Islands, which consist of ancient metamorphic rocks covered by Mesozoic and younger deposits, may be regarded as the surviving remnants of this land mass, of which the western edge is still preserved in the crystalline rocks of the Piedmont Belt of the southern Appalachians, the Florida platform, covered by younger rocks, and a part of the New England and Newfoundland uplands in the north.

The central axis of Appalachia, the location of which was probably near to or outside of the present eastern coast of the continent, rose to mountainous heights, as is clearly indicated by the nature of the sediments derived from it and by other considerations. Not the least of these was the fact that the mountains were able to shut out the moisture-bearing winds from the Atlantic so that the western slopes of the land mass were repeatedly subjected to the conditions of at least semi-aridity, even though water bodies lay to the west of it (Fig. 1003). This fact, also, points to the prevalence at that time of easterly winds over much of the area lying at present within the belt of the westerlies. The fact of repeated semi-aridity of climate along the western slopes of Appalachia is clearly demonstrated by the abundance of clastic sediment which often forms extensive alluvial fans, by the frequent red color of these sediments, and by the presence of salt deposits. The value of all of these characters as indicators of climate has already been discussed at some length in previous chapters. (See pp. 459, 491, Pt. I.)

It was Appalachia which furnished nearly all the clastic material which became embodied in the sediments of the Palæozoic of eastern North America. The bulk of this sediment was deposited in a geosynclinal trough which paralleled the western border of Appalachia and which was undergoing slow subsidence as deposition progressed. This trough at first extended southward across the western half of the Gulf of Mexico and across what is now Central America to the Pacific of that time (see Fig. 1032, p. 236), the waters of which repeatedly invaded the geosyncline from the south. On the north this trough appears to have been open sometimes to the Arctic region, and later to the north Atlantic in the New England-Newfoundland region, so that these waters as well

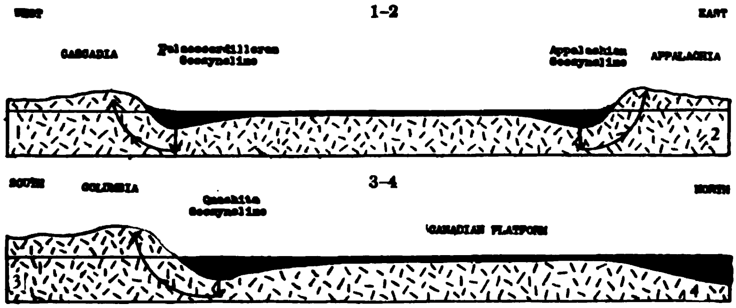


FIG. 1003. — East-West and North-South sections of the North American continent, showing the relation of the geosynclines to the Canadian platform or shield and to the oldlands. Areas of sedimentation in black. The arrows indicate direction of movement of material within the earth's crust to establish isostatic equilibrium. Upper horizontal line indicates sea-level. Vertical scale much exaggerated. (Original.)

were able to enter the geosynclinal depression. During periods of pronounced depression, the invading seas spread westward as shallow water bodies over the flat lands of the interior, while during periods of reverse movement, or relatively stationary conditions, these lands were uncovered again, and the waters may even have withdrawn entirely from the Appalachian geosyncline. At the close of the Palæozoic, the strata of the old geosyncline were folded to form the new-born Appalachian Mountains.

Atlantica. — A land mass of considerable extent and long duration occupied a part of the present north Atlantic region; its western border included eastern Canada to the shores of Hudson Bay and the region of the Adirondack Mountains of New York as well. (See Fig. 1186, p. 336.) On the whole, this land was low in the west and was repeatedly flooded by the expansion of the epeiric seas, but its eastern portion, which included at one time or another the old rocks of northwest Europe, appears to have been of bold relief and was the principal source of the clastic sediment for that region.

Cascadia and the Cordilleran Geosyncline. — Another important though less well-known Palæozoic land mass, to which the name Cascadia has been applied, occupied the western border of the North American continent, extending for an unknown distance into the Pacific of to-day. Along its eastern margin lay the Cordilleran geosyncline in which the principal western Palæozoic deposits were laid down, and from which the transgressing sea spread eastward until it met the westward-spreading Appalachian sea in the region of the present Rocky Mountain Front Range. On the south, the Cordilleran and Appalachian geosynclines probably communicated at times by means of a transverse geosynclinal depression extending through Arkansas and the southern Gulf States. At other times, however, the eastern and western geosynclines seem not to have been in communication. Later in the Palæozoic, the outlet to the Pacific across Central America was closed, extensive land masses, the source of much clastic material, occupying the Gulf of Mexico region, the present deep character of which is of recent origin. The Cascadian geosyncline may, for a time, have communicated with the Pacific across southern California, but its main communication was with the ocean to the northwest. Toward the close of the Palæozoic, the rocks formed in this geosyncline were folded, giving rise to the Palæozoic Cordilleran Mountain chain.

The Canadian Shield. — The central low-lying land, formed by the surface of the old Laurentian Peneplane and its later modifications, was, as we have seen, repeatedly flooded by the expansions of the waters from the geosynclines. There was, however, at various times a transgression of the sea from the Arctic regions, and it was apparently along this channel that communication with the seas which then covered central Europe was maintained.

Palæozoic Land Masses of Europe

The main Palæozoic land mass of Europe was Atlantica, situated on the northwest. This probably suffered various additions and subtractions during this era, but remained, on the whole, the principal source of clastic sediment. This land mass involved central Scotland and Scandinavia, and along its southeastern border a geosyncline was developing with the progress of sedimentation, and in this the principal Palæozoic deposits of the British Isles and of the Baltic region accumulated. This geosyncline opened on the one hand to the Atlantic on the southwest, and on the other to the sea which then covered part of Siberia and which was an extension from the Arctic. The southern part of Europe appears to have been a continuous land mass in early Palæozoic time, except for a marked embayment in the Mediterranean

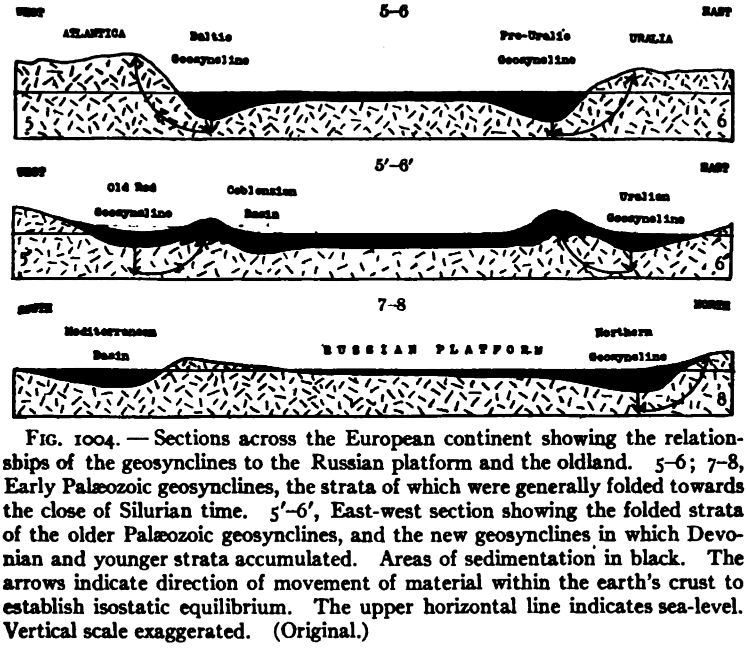


Fig. 1004. — Sections across the European continent showing the relationships of the geosynclines to the Russian platform and the oldland. 5–6; 7–8, Early Palæozoic geosynclines, the strata of which were generally folded towards the close of Silurian time. 5′–6′, East-west section showing the folded strata of the older Palæozoic geosynclines, and the new geosynclines in which Devonian and younger strata accumulated. Areas of sedimentation in black. The arrows indicate direction of movement of material within the earth's crust to establish isostatic equilibrium. The upper horizontal line indicates sea-level. Vertical scale exaggerated. (Original.)

region. Over this relatively low-lying land the sea transgressed both from the north and the west, so that overlapping deposits of varying age are found upon the old rock in this region. In later Palæozoic time the Baltic embayment was closed on the Atlantic side, while the Mediterranean embayment extended westward through southern Europe into Asia. (Fig. 1004.)

Palæozoic Seas and Land Masses of Asia

In early Palæozoic time, central Siberia was occupied by an embayment from the Arctic Ocean, extending south to the Chinese border near the city of Irkutsk. Its southeastern border is marked approximately by Lake Baikal, from which it extended north to the bend of the Lena River above the 60th parallel of latitude. Its western border is marked in general by the present course of the Yenisei River. Surrounding this Irkutsk basin or amphitheater was a rim of oldland of pre-Cambrian rocks from which sediments were largely derived. Parallel to

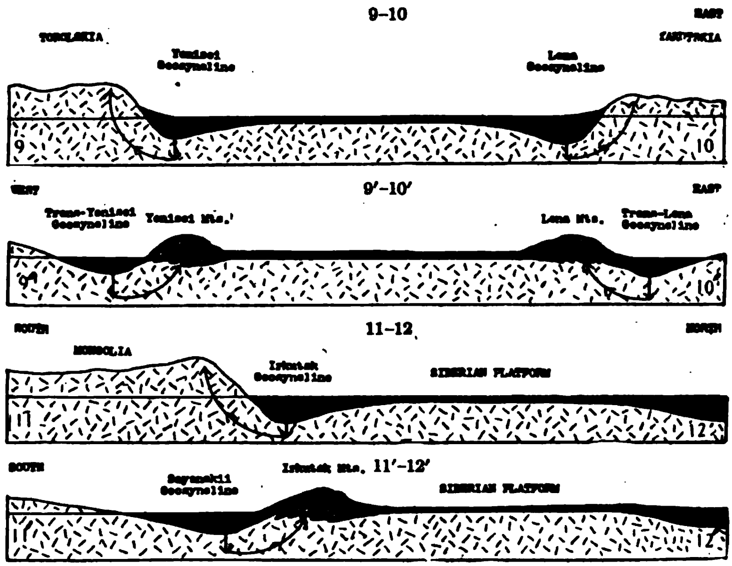


FIG. 1005. — Sections across Asia, showing the relationships of the geosynclines to the Siberian platform (Irkutsk basin) and to the oldland in Palæozoic time. 9–10, 11–12, Early Palæozoic geosynclines the strata of which were folded towards the end of Silurian time; 9′–10′, 11′–12′, Devonian and younger Palæozoic geosynclines formed in the oldland after the folding of the Silurian and older strata. Areas of sedimentation in black. The arrows indicate the direction of movement of material within the earth's crust to establish isostatic equilibrium. The upper horizontal line in 9–10, 11–12 represents sea-level. Vertical scale much exaggerated. (Original.)

this oldland rim and forming the margin of the basin, a geosynclinal depression appears to have existed, and these three elements — enclosing highland, semi-circular geosyncline, and low central basin — were thus in a general way similar to, though of less areal extent than, the later North American series where the Appalachian and Cordilleran geosynclines, joined by the transverse trough across Arkansas and Oklahoma, made a close parallel to the Siberian geosyncline (Fig. 1005). In the Siberian basin, however, only the earlier Palæozoic strata, including the Silurian, were deposited, after which the strata of the geosyncline were folded and a new geosyncline was formed to the south and west, in which Devonian and later sediments were deposited. Some of the later Palæozoic continental beds also were laid down in the Irkutsk basin, but no further marine invasion affected this area until Mesozoic time. It remained a land mass throughout the later Palæozoic. (Fig. 1005 $^{9'-10'}$, $^{11'-12'}$.)

A second embayment from the North Pacific covered parts of China in early Palæozoic time, but the areal extent of this embayment is still unknown. Finally the Indian Ocean transgressed partly over western India in early Palæozoic time.

With these general outlines of Palæozoic seas and lands in mind, we may now proceed to a more detailed study of the characteristics of the several subdivisions of the Palæozoic.

CHAPTER XXXII

THE CAMBRIAN OR CAMBRIC

We have seen that the name Cambrian formation was first applied by the Reverend Adam Sedgwick, Professor of Geology in Cambridge University, England, to the oldest stratified rocks of North Wales, the name being derived from the Roman designation of this region, the province of Cambria. Wales is a mountainous country of much disturbed rocks; the folding of the strata has been intense and has taken place repeatedly. The country has been much broken by faults and there have been many igneous intrusions and lava flows, especially in the northwestern region. In spite of this, the rocks have been metamorphosed only to a limited degree, so that the old shales and sandstones, the grauwackes or greywackes of the older geologists, and the old limestones still preserve their fossils, although these are often distorted and crushed. It was in such a difficult country that Sedgwick worked out the order of succession of the oldest fossiliferous rocks, and established the basal system of the Palæozoic as generally understood.

Cambrian rocks also occur in southwestern Wales, and they have been found in some of the eroded domes and anticlines in western England. In the far north of Scotland, where the waves of the north Atlantic, parted by Cape Wrath, have cut sections in the rocks that form the northern and western coasts, and where the ancient rivers and the glaciers have carved deep and wild lochs, these ancient rocks are again seen in many a bold cliff. But they differ markedly from those of North Wales, for instead of greywackes, the North Scottish series is formed of great masses of sandstone, often nearly white, followed by fine-grained limestones, and the deformations of these rocks are much less profound than are those of Wales. Their fossils also are quite distinct, for they belong to a separate province of the ancient Cambrian sea, as we shall see more fully presently.

On the continent of Europe, we meet with Cambrian strata around the borders of the older lands of crystalline rocks. Foremost in importance are those of Scandinavia, especially Sweden, for although the rocks there never reach such great thicknesses as they do in Wales, they are finer grained and richly fossiliferous. Moreover, they have been disturbed only to a very slight extent, and thus their superposition and relationships can readily be determined. The abundant fossils in them made a subdivision into smaller groups feasible, and partly on this account the Swedish Cambrian rocks have gradually come to be regarded as the most typical on the European continent. Their extension into Baltic Russia has enlarged the value of these deposits to the stratigrapher, who finds there older members of the series not seen in Sweden.

Next in importance in European localities is the basin of Bohemia, where these rocks, though somewhat disturbed, still retain their fossils in a remarkable state of perfection. It was Joachim Barrande (portrait, Fig. 743, p. 13) a French exile, whose studies gave to these older Bohemian rocks a world-wide fame. True, the series is not as complete as it is in Sweden, for the oldest and youngest Cambrian beds are absent, only the Middle Cambrian being represented. But these middle beds are so richly fossiliferous, and their fossils are so perfect, that central Bohemia easily takes the first rank in point of interest and importance in European Cambrian localities. There are a number of other European regions where Cambrian rocks are found, notably, among these, Spain and the Island of Sardinia, where great limestones of this age predominate. These occurrences, like the others already mentioned, are only remnants left after ages of erosion of the beds formed during the Cambrian. Their former extent, so far as can be determined by a variety of evidence, is indicated upon the palæogeographic maps. The student must not forget that these beds, when formed, were nearly horizontal sheets of sand, mud, and lime, deposited upon the floor of a shallow sea, which at that time covered these regions, and that the folding and fracturing, and the elevation of these rocks, occurred after their consolidation, and that since that time they have been subjected to erosion for millions of years, so that the wonder is that so much of the formation still remains.

Cambrian rocks still cover large areas of eastern Asia, extending far north into the arctic region of Siberia. They form in part the surface rock, while other portions are buried under younger strata. These Asiatic Cambrian rocks have as yet been studied only to a limited degree, but enough is known to show that there, as in Bohemia, the Middle Cambrian is more frequently present than either the Lower or Upper. In Australia, India, and Antarctica, Cambrian sediments are likewise preserved, but only in isolated areas, and deposits of this age are also found in South America.

In North America, the Potsdam sandstone, which lies directly upon the crystallines of the Adirondack Mountains, was long supposed to be the oldest sedimentary rock, and it was taken to represent the base of the New York System of Formations.


FIG. 1006. — EBENEZER EMMONS.

Ebenezer Emmons (portrait, Fig. 1006), however, believed that the rocks which formed the Taconic Mountains on the New York-Massachusetts border, and the equally disturbed rocks of western Vermont, belonged to an older system, which should take its place between the Potsdam sandstone and the crystalline basement rocks. Though vigorously opposed by most geologists of his day, his general contention has proved correct, and we now know that the Taconic system of rocks, as he called it, though including infolded and infaulted masses of younger rocks (Ordovician) is essentially the American representative of the Cambrian system of Europe, while the Potsdam sandstone represents the very highest member of this division, the basal sandstone of an overlapping series of formations. The following diagram (Fig. 1007) represents this relationship in very generalized form. These disturbed rocks belong to the deposits of the Appalachian geosyncline, of which the Adirondack region forms the western border, and they therefore present only the highest overlapping members of the Cambrian series (the Potsdam sandstone). Both to the north and the south, Cambrian rocks of greater thickness, and often highly calcareous, form part of the series of sediments of the Appalachian geosyncline. The most noted localities in the north are in western Newfoundland and on the shores of Labrador, while on the south many localities, from New Jersey and Pennsylvania to Alabama, show these rocks in outcrop. For the most part they have all been much disturbed, though the disturbance in the southern Appalachians is not so profound as that in the northern extension. These northern deposits appear to

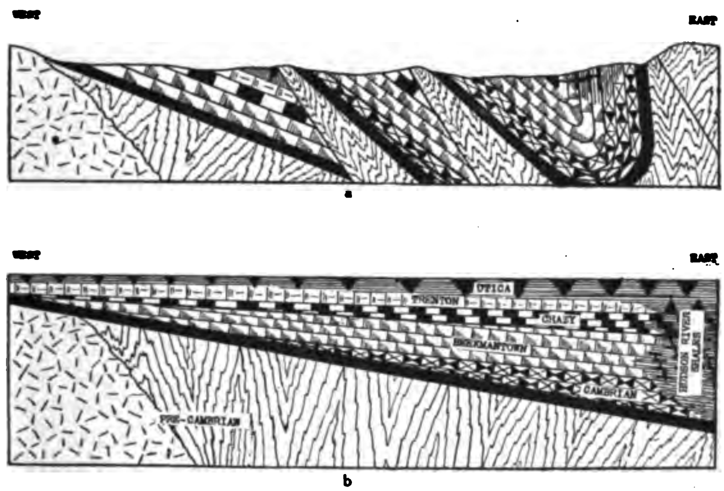


FIG. 1007. — (*a*) Generalized section showing the approximate relationships of the pre-Cambrian, Cambrian, and early Ordovician strata in the Taconic Mountain region. Note that in the different fault blocks different formations succeed the basal sandstone (black). (*b*) Ideal or restored section to show the relationships of these strata before folding and faulting. Note that on the west limestones succeed the basal sandstone, while eastward the sands and muds from Appalachia take their place, forming the Hudson River shales and sandstones. (Original.)

have been at one time continuous with those of north Scotland, with which they are in close accord.

Of equal significance, for North American geology, are the Cambrian deposits which were formed on the Atlantic side of the Appalachian oldland, and remnants of which are preserved in eastern Newfoundland, Cape Breton, and New Brunswick (the Canadian region), and at several places in eastern Massachusetts (Nahant, Braintree, Weymouth, North Attleboro, etc.). Though also disturbed, more so in some sections than in others, they contain well-preserved fossils, especially in the Canadian provinces, and here too a subdivision similar to that made in Scandinavia is possible and has been carried out in great detail by Dr. George F. Matthew. The series corresponds very closely to that of

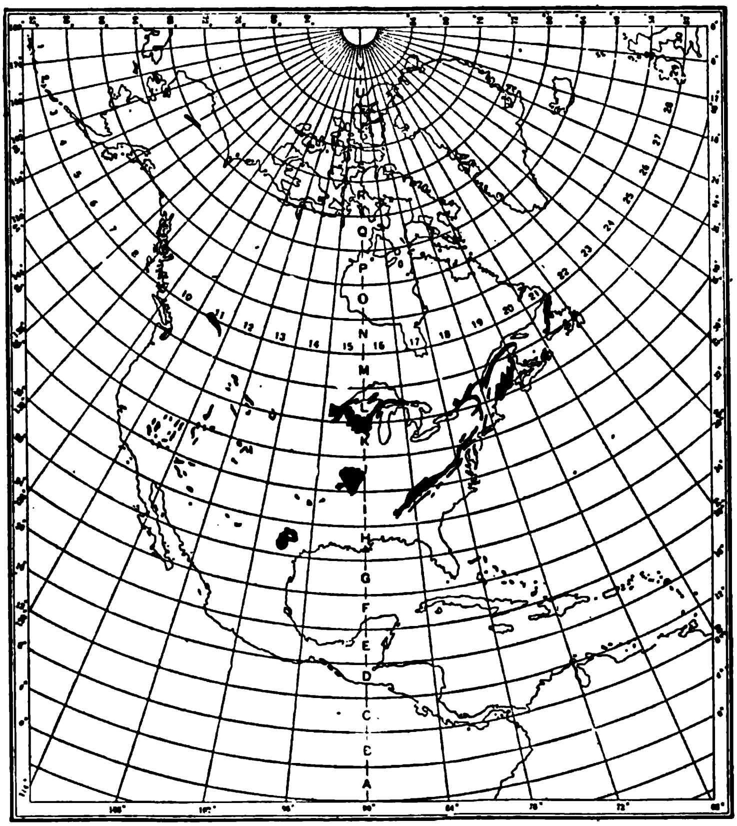


FIG. 1008. — Map of North America, showing the outcrops of the Cambrian and early Ordovician rocks. (After Bailey Willis, U. S. G. S.)

Sweden, because these two regions belong to the same province (the Atlantic).

By far the greatest development of Cambrian rocks in North America is, however, found in the deposits of the Cordilleran trough, and the remnants preserved to-day in southeastern California, in Nevada, and in the mountains of Utah and the Canadian Rockies are the most extensive and most complete in the world so far as is known. Some of these contain fossils in a surprising state of perfection, for the soft parts of the animals are in many cases recognizable by their impressions, a condition of preservation seldom met with even in rocks of much younger age. They have been made the subject of prolonged study by Dr. Charles D. Walcott, secretary of the Smithsonian Institution (Figs. 1039–1041).

Cambrian beds are also met with in the interior of North America. Wherever the old crystallines appear as the surface rocks in the United States they are generally bordered by beds of Cambrian age, though in some cases these are overlapped by beds of younger age (Ordovician). In some sections, as in Minnesota and Wisconsin, and along the Rocky Mountain Front Range, the beds next above the crystallines are the highest Cambrian (essentially of the age of the Potsdam sandstone, Figs. 979–980, 982–984), but in other cases, as in the Ozark Mountains, the Arbuckles, and Central Texas (Burnett Uplift, Fig. 981), they are older Cambrian rocks. Finally, it must be realized that in most places in our country where the surface rocks are of younger than Cambrian age, they bury beneath them the Cambrian strata, which generally (though not always) are the first which rest upon the crystalline basement (Map, Fig. 1008).

With these general facts of distribution in mind, we may now proceed to study the rocks and fossils of this system in greater detail.

General Characters of the Cambrian Transgression

In all parts of the world now known, the Cambrian rests either directly and unconformably upon the much eroded crystallines or the folded Algonkian strata, or it rests with a disconformable contact upon late pre-Cambrian continental sediments, as in the region underlain by the Belt Terrane and in some other sections of the earth's crust. The Cambrian thus represents the first undoubted great transgression of the seas over the continents, for the assumed transgressions in pre-Cambrian time are still without the positive evidence afforded by undoubted marine fossils, except for the presence of Foraminifera and Radiolaria in some of the ancient rocks of Brittany. In any case, however, whether or not there are extensive pre-Cambrian marine formations, all the known continents were dry land and subject to erosion at the opening of

Cambrian time, so that we find everywhere a distinct break at the base of the Palæozoic as now constituted. The first Cambrian sediments, to be sure, were not everywhere marine, for in a number of localities, especially in the southern part of the Appalachian geosyncline and elsewhere, great masses of sand and pebbles were deposited by rivers in the form of alluvial fans, before the encroaching sea reached those areas. Moreover, as has already been stated (page 186), the encroaching sea found, nearly everywhere, deposits of residual sand resting upon the eroded surface of the oldland, and these sands it reworked more or less throughout, and formed of them its first deposits. This is clearly shown by the fact that the Cambrian practically everywhere in North America and Europe begins with a basal sandstone, or more rarely a conglomerate. It may be well for us to note again the reasons for concluding that this basal sand was found by the encroaching sea, and was not, except in a few cases, the first product of marine erosion.

The material of this basal sandstone is generally a pure quartz sand, though in some sections little-altered feldspar crystals also occur, giving it an arkosic character. If this sand were the product of erosion by the encroaching sea, or were washed into it by rivers bringing the complete product of sub-aërial decay of the old crystalline basement rocks, there should be present somewhere a large amount of fine material, partly rock-flour and partly clay, the latter resulting from the decomposition of the feldspars. This fine material would be washed out of the sand by the waves and carried seaward by the currents, and as a result, the next deposit above the basal sand in most regions should be a mud-rock or shale. But this is not the case, especially over most of eastern and central North America, where the basal sandstone is succeeded by and generally passes upward into, a limestone or dolomite of increasing purity, free, as a rule, from argillaceous material. Therefore we must conclude that this fine material was removed before the advent of the sea, and in general was carried out of the reach of its advance, leaving behind the pure sand. The only agents, other than the sea waves, competent to remove such fine material are rivers and wind. If these agencies reworked the sand during the process of removing the finer material, they would impress upon it certain definite structural characteristics, most marked of which would be cross-bedding, both of the torrential and eolian type. If the sand were entirely reworked by the transgressing sea, this structure would, of course, be destroyed; but if the original deposit were very thick in an area of depression, only the upper portion might be reworked, leaving the original torrential or eolian structure intact in the lower part. In conformity with this principle, we find that where the basal bed is very thick, as in the eastern Adirondack region, the lower part still retains its cross-bedded structure.

When sands which are subjected to wind-drifting encounter pebbles and boulders, these, we have seen (p. 406, Pt. I) become faceted, that is, definite faces which intersect in blunt angles will be carved upon them by the wind-borne sand. Such faceted pebbles (*Dreikanter*) are clearly indicative of wind work, but if a sand deposit containing them is much reworked by the encroaching sea, the sharpness of outline of the facets and their intersection will be destroyed by wave erosion. Now, as we have noted before, such faceted pebbles, showing very little wear, are found in the basal Cambrian sandstone of Sweden in some abundance, while fossils are occasionally found, showing that the sand was reworked by the sea. The slight wear of the pebbles, however, indicates that this reworking was neither prolonged nor profound.

Having established the fact of a marine transgression over countries the rock surfaces of which were covered more or less widely by residual sands, we may next inquire as to the rate of this transgression — was it rapid or slow, continuous or interrupted by periods of retreat? If the transgression were rapid, large areas of territory would be flooded almost simultaneously, especially if the surface of the submerging land were relatively flat. In that case, the marine organisms which would become embedded in the basal sands, and in the sediments immediately succeeding, would be of the same species everywhere, indicating the same geological age. In other words, the basal bed over the entire flooded area would represent essentially the same geological horizon. If, on the other hand, the transgression of the sea were slow, the basal bed would not be of the same age throughout, for different parts of the surface would be submerged at sufficiently long intervals of time to permit a change in the character of the organisms which would be included in the deposits at the successive stages.

If, then, the basal sandstone at one locality contains only Lower Cambrian fossils, and at another only Middle Cambrian fossils, we are compelled to conclude either that the second locality was dry land while the Lower Cambrian deposits were forming in the first, and that it did not become submerged until Meso-Cambrian[1] time, or that if any Lower Cambrian deposits had been formed there, they were worn away again before the submergence of this region in Meso-Cambrian time. In that case we should expect to find evidence of withdrawal and readvance of the sea in the form of an erosion plane between the Middle and Lower Cambrian beds at some locality where the lower beds had not been wholly removed by erosion.

Noting the age of the basal sandstone in different parts of North America or Europe, as indicated by its fossils or the fossils in the beds immediately overlying it, we are forced to conclude that in general there was a progressive advance of the sea throughout Cambrian time, some regions becoming submerged only in Mid-Cambrian time, and others, of very much greater extent, only in later Cambrian time, though as we shall see there were also periods of retreat, with erosion, followed by readvance. On the whole, however, the successive divisions of the Cambrian of the North American continent overlap one another in a direction which in general is from the geosynclines toward the interior of the continent.

Subdivision of the Cambrian

Wherever the Cambrian system is fully developed, a considerable number of formations may be recognized in it, based usually upon lithologic characters but also on fossil contents. These formations are mostly of local value only, but they can always be grouped into three major divisions which represent the Lower, Middle, and Upper Cambrian deposits made in early, mid-, and later Cambrian time, respectively.[1] These three divisions are based upon the three-fold character of the Cambrian fauna, which is perhaps more marked in this respect than is the case in most later systems. As we have seen, however, these three divisions are not present everywhere, for by overlaps the higher ones (Middle or Upper Cambrian) in some regions came to rest directly upon the surface of the oldland.

[1] It is customary to use the prefixes *palæo-* (early), *meso-* (mid-), and *neo-* (new or later) for the time periods corresponding, respectively, to the *Lower*, *Middle*, and *Upper* divisions of the rock systems.

Cambrian Faunas

Separate Faunal Provinces. — In the study of the Cambrian faunas it becomes apparent that there are distinct faunal provinces,

a b

Fig. 1009. — *Archæocyathus rensselæricus*, Cambrian. *a*, Specimen with cup partly broken so as to show poriferous character of inner wall; *b*, transverse section of upper end further enlarged. (After Walcott.)

Fig. 1010.— *Ethmophyllum profundum*. Longitudinal section, showing depth of cup and vesicular structure. Cambrian. (After Walcott.)

and that the organisms of one have little or nothing in common with those of the others, which would indicate the existence of effective barriers between those provinces, such barriers being either

Fig. 1011. — *Medusites lindströmi*. A medusa, natural cast. Cambrian of Sweden. (After Linnarsson.)

FIG. 1012. — *Dactyloidites asteroides*. A medusa compressed on shale. Cambrian. (After Walcott.)

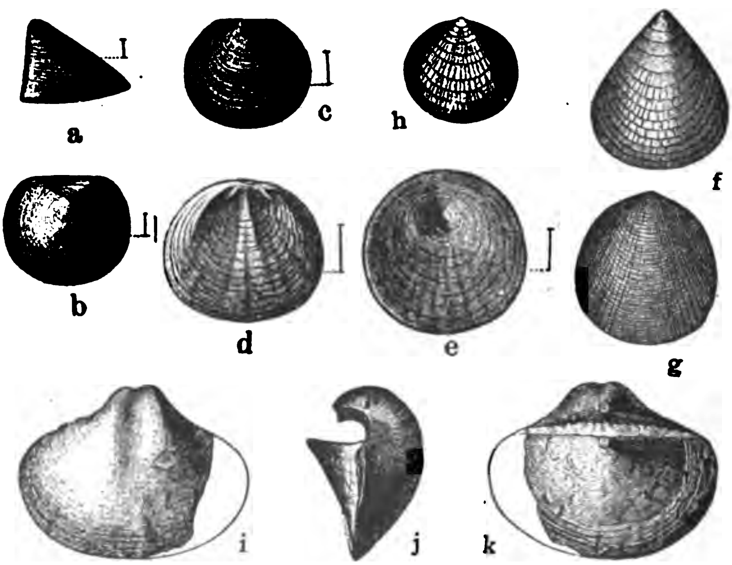


FIG. 1013. *a–j*. — Lower and Middle Cambrian Brachiopoda. *a–c*, *Acrotreta gemma* (*a*, *b*, pedicle; *c*, brachial valve, × 3); *d*, *e*, *Acrothele subsidua*, interior of brachial, exterior of pedicle valve, × 3; *f–h*, *Obolella gemma*, opposite valves, × 6; *i–k*, *Kutorgina cingulata*, enlarged.

land, currents, etc., or climate. The known provinces are the Pacific, the Atlantic, and the Indian. The Pacific province was

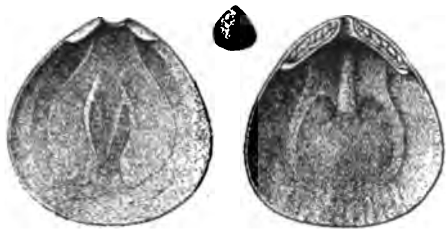


FIG. 1014 *a*. — *Obolella* (*Dicellomus*) *politus*. Natural size and interiors of opposite valves, much enlarged. Potsdam sandstone. (After Hall and Clarke.)

FIG. 1014 *b*. — *Lingulepis acuminata*. Pedicle valve, × 2. Potsdam sandstone. (After Walcott.)

the largest, and in North America, waters from this province filled the geosynclines and transgressed over the low land between. On the other side of the ocean, it overlapped Chinese territory, for fossils, often of the same species as those characteristic of the North American Cambrian of this province, have been found in China.

FIG. 1014 *c*. — *Lingulepis acuminata*. Internal molds of pedicle and brachial valves, × 2. Potsdam sandstone. (After Hall and Clarke.)

The Atlantic province was separated from the Appalachian geosyncline, which belonged to the Pacific province extension, by the land mass of Appalachia. This appears to have extended through the center of Newfoundland, for in the western part of that land deposits

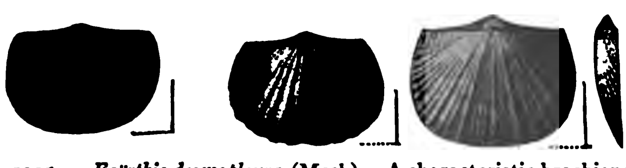


FIG. 1015. — *Eoörthis desmopleura* (Meek). A characteristic brachiopod of the uppermost Cambrian. Colorado. (After Bassler.)

of the Pacific province are found, while in the extreme eastern part those of the Atlantic province occur. Other deposits of the Atlantic province are still preserved in Cape Breton, New

Brunswick, and eastern Massachusetts, while on the opposite side of the ocean, the Anglo-Baltic geosyncline and a second em-

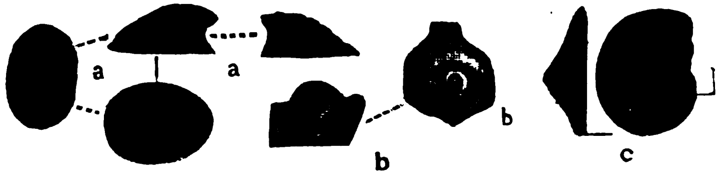


FIG. 1016. — Lower Cambrian Gastropoda. *a*, ***Helcionella rugosa***, 3 views and ground plan; *b*, ***Straparollina remota***, 2 views; *c*, ***Raphistomina attleboroughensis***. All enlarged. (I. F.)

bayment, the Mediterranean, which extended to Bohemia, contain deposits with the Atlantic fauna. Of much interest is the fact that

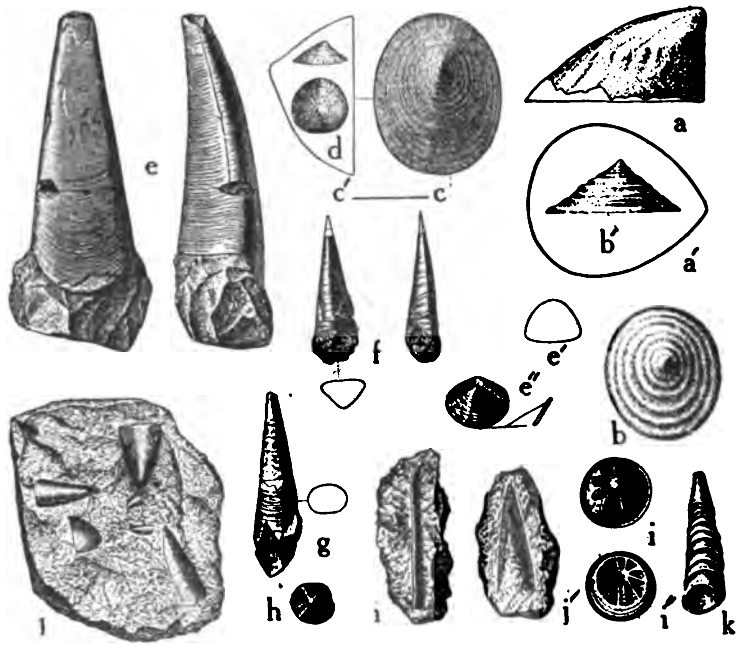


FIG. 1017. — Cambrian gastropoda (*a–d*), and Hyolithids (Conularida) (*e–k*). *a*, ***Triblidium convexum***, side and bottom outline, U. C.; *bb'*, ***Palaeacmaea typica***, U. C.; *c*, *Scenella reticulata*, top view and outline, L. C. (× 2⅔); *d*, *Scenella retusa*, L. C. (reduced); *e*, *Hyolithes princeps*, 2 views: cross-section (*e'*) and operculum (*e''*), L. C. (× ⅔); *f*, *H. billingsi*, 2 views and section, L. C. (× 2); *g*, *H. impar* and sections, L. C.; *h*, *H. communis*, operculum, L. C.; *i*, *Hyolithellus micans*, L. C. (× 2); *i''*, two opercula interiors (× 3); *j*, *Salterella pulchella*, and section *j'*, L. C. (× 2); *k*, *S. rugosa*, L. C. (× 3). (L. C. = Lower Cambrian; M. C. = Middle Cambrian; U. C. = Upper Cambrian.) (I. F.)

while the deposits of Wales and the adjoining English districts belong to the Atlantic type, those of northwest Scotland belong to the Pacific type, indicating that a sufficiently continuous barrier extended for part of the time, at least, from central Newfoundland to the Scottish Highlands and thence to Scandinavia, and that the Appalâchian geosyncline was continued to the north of this barrier (Figs. 1032, 1038). The Indian province was distinct from both the others.

FIG. 1018. — *Eophyton* (× ½) from the Lower Cambrian of Lugnås, Sweden. (From Haug.)

General Characters of the Cambrian Fauna. — A general review of the Cambrian fauna brings out certain striking characteristics. Typical **sponges** and **corals** are rare or absent, though there is one group common in certain localities which has been referred sometimes to one and sometimes to the other class; for example *Archæocyathus* and related forms (Figs. 1009, 1010) which in some regions occur in such abundance as to form reef limestones. **Graptolites**, too, are unknown except in the highest beds, which are, therefore, often placed in the base of the Ordovician. **Jellyfish**, however, appear to have been common, though they are preserved only under most favorable conditions (Figs. 1011, 1012). **Bryozoa** are still unknown in the Cambrian, but **brachio-**

pods are not uncommon. They are, on the whole, of the more primitive hingeless types, the shell of which is but little impregnated with lime and is often

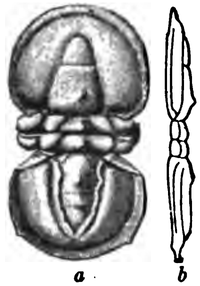


FIG. 1019 *a, b.* — *Agnostus interstrictus.* (*a*) top and (*b*) side view enlarged. (After Walcott.)

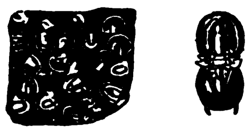


FIG. 1020.—*Agnostus pisiformis,* dissociated parts (natural size) and individual enlarged. Upper Cambrian. (After Kayser.)

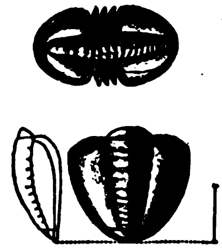


FIG. 1021. — *Microdiscus speciosus,* entire individual, and pygidium enlarged. Lower Cambrian. (I. F.)

phosphatic, so that it generally fossilizes as a shiny black and thin layer. Among the common forms are the subspherical *Obolella* (Figs. 1013 *f–h,* 1014 *a*), the

FIG. 1022.—*Olenellus thompsoni* (reduced). Lower Cambrian, Pacific province. (I. F.)

FIG. 1023. — *Holmia bröggeri* (reduced). Lower Cambrian, Atlantic province. North America. (I. F.)

more elongated *Lingulepis* (Figs. 1014 *b, c*), the conical *Acrothele* (Figs. 1013 *d, e*), *Acrotreta* (Figs. 1013 *a, c*), and *Kutorgina* (Figs. 1013 *i–k*) and some others.

FIG. 1024. — *Holmia kjerulfi.* Lower Cambrian, Atlantic province, Europe. (Kayser.)

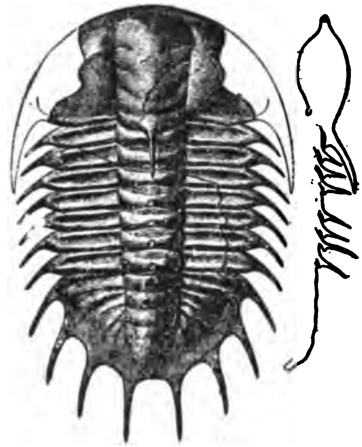


FIG. 1025. — *Olenoides curticei.* Middle Cambrian, Pacific province. (I. F.)

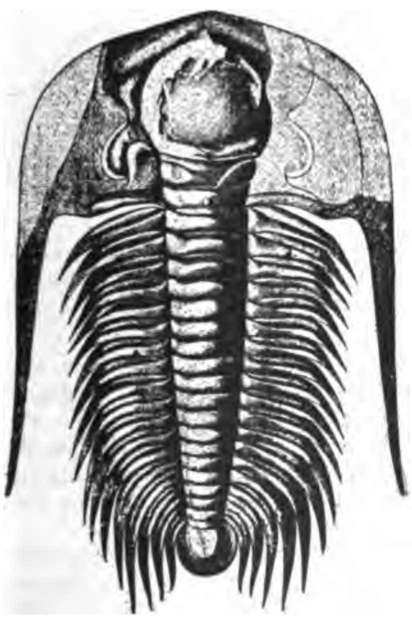
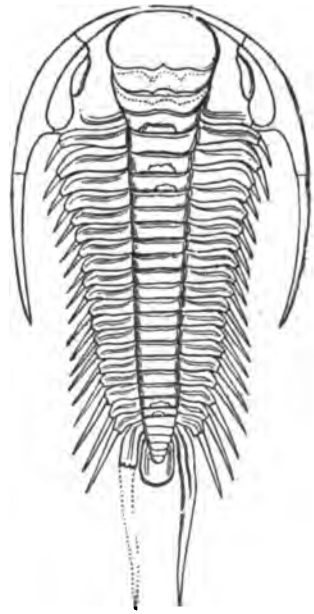


FIG. 1026. — *Paradoxides harlani.* Middle Cambrian, Atlantic province, Massachusetts; × ½. (I. F.)



1 (½)

FIG. 1027. — *Paradoxides bohemicus.* Middle Cambrian, Atlantic province, Bohemia; × ½. (Kayser.)

Toward the top, in beds sometimes placed in the basal Ordovician, **brachiopods** of the *Orthis* group with true hinge area and articulation appear (Fig. 1015). **Pelecypod** shells are hardly known, and **gastropods** are mainly represented by the cap-shaped or patelloid types (*i.e.* more or less conical forms) *Helcionella* (Fig. 1016 *a*), *Palæacmæa*, *Scenella*, etc. (Figs. 1017 *a–d*). A few simple coiled forms occur, however, such as *Straparollina* (Fig. 1016 *b*), *Rhaphistomina* (Fig. 1016 *c*). **Cephalopods** are wanting in the Cambrian except for a small primitive orthoceran type (*Volborthella*). The group of the **Conularidæ** is, however, well represented, especially by *Hyolithes* (Figs. 1017 *e–h*) and related forms

FIG. 1028. — *Crepicephalus texanus*. Middle Cambrian, Texas to Alabama, and Wyoming. (Reduced.) (I. F.)

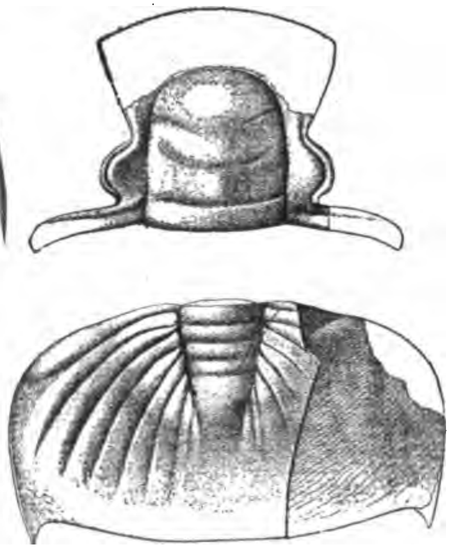


FIG. 1029. — *Dicellocephalus minnesotensis*, head and pygidium (reduced). Potsdam (St. Croix) sandstones. (I. F.)

(Figs. 1017 *i, j, k*). The **echinoderms** are rare, though primitive cystoids have been found as well as remains of holothurians or sea-cucumbers. The highest beds, Tremadoc, also often referred to the Ordovician, contain the earliest known crinoids and starfish, as well as sponge remains and graptolites; **worms** also existed, but are mostly represented by their tubes in the sandstones (*Scolithus*, Fig. 762, p. 43, *Eophyton*, Fig. 1018, and others. See also Figs. 1040, 1041).

By far the largest element of the fauna was made up of **trilobites**, of which many species have been described. Some of these were minute *Agnostus* (Figs. 1019, 1020) and *Microdiscus* (Fig. 1021), their remains sometimes making up thin beds of limestone, while others reached a length of over a foot and a half (*Paradoxides*, Figs. 1026, 1027). These animals are the most serviceable in distinguishing the different divisions of the Cambrian and at the same time the several provinces. While many types occur in each division, the most diagnostic genera are the following: —

	Pacific Province	Atlantic Province
Upper Cambrian	*Dicellocephalus* (Fig. 1029)	*Olenus* (Fig. 1030)
Middle Cambrian	*Olenoides* (Fig. 1025)	*Paradoxides* (Figs. 1026, 1027)
Lower Cambrian	*Olenellus* (Fig. 1022)	*Holmia* (Figs. 1023, 1024)

These names are used in their broader significance, for several of the genera have subgenera or closely related genera which go by other names and which replace the typical forms in some sections. Another characteristic American genus is *Crepicephalus* (Fig. 1028).

Other **crustaceans** also occur, but are of little value as index fossils on account of their rarity. The remains of a few **eurypterids** have been obtained, showing that the group was well developed. They probably lived in the rivers of the time, as did those of later periods and those of the Belt Terrane deposits as well. No **fish** or higher types are known. Of Cambrian plants, only **algæ** are known (Fig. 1031, see also Figs. 1462–1465, pp. 538–540).

Fig. 1030. — *Olenus truncatus.* Upper Cambrian, Atlantic province. (Kayser.)

Fig. 1031. — *Marpolia æqualis* Walcott. A fossil alga from the Middle Cambrian. (Stephen formation, "fossil bed," northwest slope of Mount Stephen. Above Field, B. C.) Portions are twisted together, giving the appearance of a central stem; × 2. (After Walcott.)

The significance of the apparent sudden appearance of many of these groups of organisms will be discussed in the summary of the life of the Palæozoic (Chapter XL).

Stratigraphic Development

Lower Cambrian Waucobian or Georgian (Fig. 1032). — The earliest invasions of the Cambrian sea upon the continents took place in the geosynclinal troughs, and hence it is in these that we find the Lower Cambrian best developed. The invasions of the two American geosynclines seem to have been primarily from the south Pacific and carried with them the *Olenellus* fauna. It is

Fig. 1032. — Palæogeographic map showing the distribution of land and sea (black) at the end of Lower Cambrian time. (Original.)

obvious that, other things being equal, the region first covered by the sea will be subject to longer submergence and to thicker deposits than regions submerged later. Thus within the same division of the Cambrian (as recognized by the fossils) some sections will be thick, and these contain the complete series of deposits because they were the first to be submerged; others will be thin, and these contain only the later members of the series, because submergence here took place much later. Difference in thickness between two sections, however, is merely an indication of difference in the time of submergence, not proof of it, for this may also be due to different rates of deposition in the two localities, especially if the material is of a different character. Difference in the time of submergence, and therefore of overlap of the formations, can only be established if it can be shown by the faunas that the thinner section includes only the upper members of the thicker section.

One of the thickest sections of the Lower Cambrian deposits (nearly 6000 feet) is found in the Cordilleran trough near Waucoba Springs in Inyo county, California, and for this reason the names Waucobian period and Waucobian division have been used for the Lower Cambrian. The deposits are largely sands which were derived from the Cascadian land mass on the west. Eastward the successive divisions of the series overlap, so that the Lower

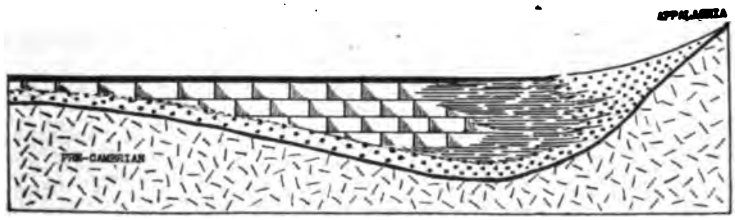


FIG. 1033. — Cross section of the Appalachian Geosyncline in Lower Cambrian time, showing the formation of sands on the east (next to the oldland of Appalachia) shales farther out, and limestones in the western part, these resting with a basal sandstone (residual) upon the crystallines. The sea is shown in black. (Original.)

Cambrian of Nevada and other regions in the Great Basin are much thinner, and represent only the upper members. Thus is indicated an eastward transgression of the Lower Cambrian sea in this trough. In the Appalachian trough the thickest deposits are found in the south. As already noted, the series often begins with conglomerates and sandstones of continental (alluvial fan) origin, the material of these deposits being derived from Appalachia. In general, sections which represent regions that were close to the oldland of Appalachia contain much sand and conglomerate, but those farther away (westward) contain mostly finer material in the form of shales, and others contain mainly limestone which follows upon the basal sandstone (Fig. 1033). This shows that sands and muds were being washed into the trough by rivers from Appalachia, and that only those portions of the trough which were not reached by these terrigenous sediments permitted accumulation of limestones. In this way the great diversity in the character of different sections is readily accounted for. Thus when we find that in northern New Jersey (Hardiston), in the Hudson River Valley north of the Highlands (Wappinger Valley), and in central Vermont, basal sandstones, sometimes with remains of *Olenellus*, are succeeded by fine-grained but pure limestones, also with characteristic fossils of the Lower Cambrian, we conclude that these localities represent a belt of the old trough sufficiently removed from the Appalachian land to be out of reach of sediments from it. When, on the other hand, we find that in northern Vermont the Lower Cambrian contains much fine shale (mud-rock) as well as limestones, we conclude that this region was within reach of the sediments washed in from Appalachia in Lower Cambrian time. Again, when we find that in western Newfoundland and in northern Scotland the basal sandstone — which in north Scotland

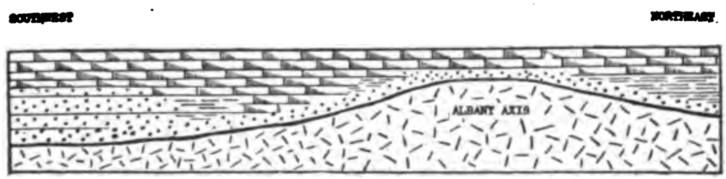


FIG. 1034. — Longitudinal section of the Appalachian Geosyncline, showing the overlaps of the Lower Cambrian strata from the south and north, against the "Albany axis" of uplift. (Original.)

contains many worm tubes, so that it is called "pipe rock," — is followed by limestones, we again conclude that these portions of the old trough were not invaded by clastic material from the land; in this case, perhaps, because the land was relatively low and narrow.

When we compare the great thickness of the Lower Cambrian formations in the southern Appalachian region with the lesser development farther north, it is at once suggested that the trough was invaded from the south, and that the transgression took place northward with accompanying overlap of successive horizons. This suggestion is confirmed by the fact that the lower beds in the southern Appalachians are of older age, as shown by their fossils (Fig. 1034).

It was in the shales of northern Vermont, near the town of Georgia, that the *Olenellus* fauna was first discovered, but it was not until long after that discovery that it was recognized as belonging to the oldest Palæozoic rocks. Then the name Georgian was proposed for this lower division of the Cambrian, and this name had become widely used before it was proposed to substitute the name Waucobian for it, because the Waucoba Springs section represented a more complete development of these formations.

Lower Cambrian of the Atlantic Province (Etcheminian).—The Atlantic province was characterized by the trilobite *Holmia* and its relatives (*Holmia* fauna), in Lower Cambrian time, and because of its distinctiveness from the Pacific province, the deposits of which carry the *Olenellus* fauna, a separate name, that of *Etcheminian*, derived from a tribe of Indians, is sometimes used for it. Remains of the Lower Cambrian of the Atlantic province have been discovered in eastern Massachusetts (Boston region), in New Brunswick, Cape Breton, and eastern Newfoundland, on the American side. On the European side (Fig. 1032) they are known from southern Britain, especially Wales, from Norway and Sweden and the Baltic provinces of Russia, all of these forming deposits of the Baltic embayment; and from Spain, Sardinia, etc., in the Mediterranean region, where they form parts of the deposits in the Mediterranean embayment. In all of these localities, except those last mentioned, shales predominate, showing that the rivers supplied mud to the northern basin although a few thin limestones also occur. In the Mediterranean region, on the other hand, thick limestones were formed chiefly by the growth of the peculiar coral or sponge-like organisms of the *Archæocyathus* group. Where these occur (Spain, Sardinia) we must conclude that the waters were free from sediment, these regions probably representing the center of the embayment.

A comparison of different sections in the Atlantic province shows that there was progressive overlap of the various members of the Lower Cambrian toward the oldland. Thus in Cape Breton, the Lower Cambrian is several thousand feet thick. Thirty miles northeast of St. John, New Brunswick, only about 1200 feet of these strata occur, while at St. John, the Lower Cambrian is wholly wanting (or replaced by continental beds), the marine Cambrian beginning with the middle division (Fig. 1035).

In southern Wales, the Lower Cambrian is a thick series of sandstones with characteristic fossils, but in north Wales, nearer the oldland, it is represented by unfossiliferous shales, sands, and grits, the latter often feldspathic and apparently chiefly of continental origin. In Sweden, usually only a thin sandstone represents this division, while in some sections the Cambrian begins with the middle (*Paradoxides*) series. In the Baltic

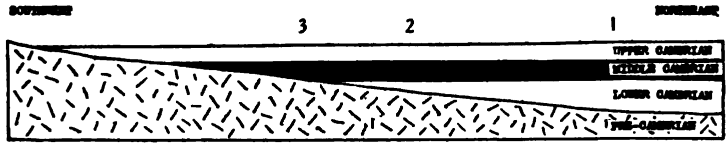
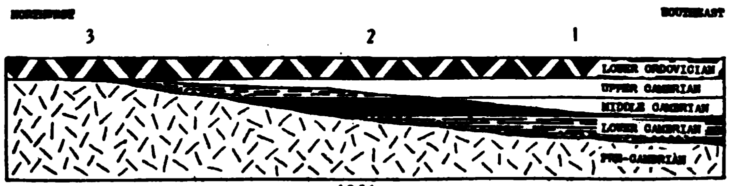


FIG. 1035. — Diagrammatic section to show the relationships and overlaps of the Lower, Middle, and Upper Cambrian formations. 1. Cape Breton Island, Lower Cambrian present in great thickness; 2. Hanford Brook, N. B., a moderate thickness of Lower Cambrian strata present; 3. St. John, N. B., the series begins with Middle Cambrian. (Original.)

provinces of Russia, the series consists of sandstones and clays, and a regular overlap may be recognized (Figs. 1036, 1037).

We thus learn that in both provinces there was a more or less continuous advance of the sea, with overlap of the several forma-



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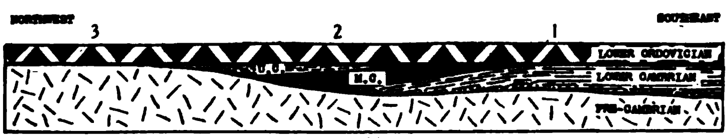


1037

FIGS. 1036 (upper) 1037 (lower). — Sections showing the relations of the Cambrian and early Ordovician strata and the overlaps in the Baltic region of Europe. The upper diagram shows the Cambrian strata essentially as originally deposited, the unshaded portion representing the part eroded during the Upper Cambrian retreat of the sea and before the readvance of the Lower Ordovician sea, and the deposition of the *Ceratopyge* beds. The lower diagram shows the relationships of the strata as they existed in early Ordovician time. 1. Baltic Province of Russia; 2. Southern Sweden; 3. Central Sweden, where the *Ceratopyge* beds rest directly upon the old granite and gneiss. (Original.)

tions of the Lower Cambrian, but that large areas of the land of that period were not covered by the sea until Meso- or Neo-Cambrian time.

Middle Cambrian or Acadian of the Atlantic Province (Fig. 1038). — The Middle Cambrian beds are best known from the Atlantic province, where they are characterized by various species of *Paradoxides*. They are particularly well developed in the Acadian region of eastern Canada, and on this account the name *Acadian* group has been adopted for this division. The deposits are nearly always shales, though some thin limestone beds also occur. There is, however, little sand except toward the top.

Other well known localities for Middle Cambrian are in eastern Massachusetts (Braintree, where these strata are intruded by the Quincy granite), in Wales and England, in Sweden and Norway, and in Bohemia.

FIG. 1038. — Palæogeographic map showing the distribution of land and sea (black) at the end of Mid-Cambrian time. (Original.)

In several sections in Newfoundland, a distinct break has been found between the Lower and Middle Cambrian deposits, the two being separated by an erosion surface, worn fragments of the Lower being included in the basal beds of the Middle division. This indicates a retreat of the sea at the end of Lower Cambrian time, or else a local uplift and erosion. Such evidences have not been found elsewhere, chiefly perhaps because the basal beds of the Middle Cambrian are seldom well exposed. It has, however, been thought that the great difference between the *Paradoxides* and the *Holmia* faunas might indicate a withdrawal of the sea from the lands for a sufficiently long time to permit the evolution of the new (*Paradoxides*) fauna, after which the sea again flooded the coastal lands. This must for the present remain a speculation.

There is, however, very clear evidence that the Middle Cambrian sea transgressed much farther than did the Lower Cambrian sea in this province, because we find that the Middle Cambrian deposits frequently, if not generally, overlap those of the Lower Cambrian. The important localities where this is shown around the margin of the Atlantic are the following:

At St. John, New Brunswick, Middle Cambrian beds rest upon the crystallines or upon continental beds, beginning with an unfossiliferous basal sandstone which, thirty miles away, where the Lower Cambrian underlies the Middle, is replaced by shale and limestone with fossils (*Protolenus* bed). In Sweden, the Middle Cambrian beds, with a basal sandstone, lie directly upon the old rocks in a number of localities. But by far the best illustration of this overlap is seen in Bohemia, the region made classic by the researches of the illustrious Barrande. Here Middle Cambrian beds are well developed and rich in fossils, but they rest directly upon an old boulder conglomerate which, in turn, lies upon the crystallines. There is no Lower Cambrian present in this region, which appears to represent the extension of the Mediterranean embayment in Meso-Cambrian time (Fig. 1038).

A unique condition is shown in the Baltic provinces of Russia, for there the Middle Cambrian beds are absent, while the Lower Cambrian itself is incomplete at the top, being followed by the very latest Upper Cambrian or earliest Ordovician. This is explained as due either to nôn-deposition of the Middle Cambrian, owing to elevation of this region, or, what is more likely, to the re-erosion of the Middle Cambrian beds in Neo-Cambrian time. Similar conditions exist in some parts of the Pacific province, and will be referred to later.

Middle Cambrian of the Pacific Province. — The Middle Cambrian deposits of the Pacific province carried an entirely distinct fauna from those of the Atlantic. No *Paradoxides* is known from the vast area covered by these deposits, although *Paradoxides* is the most abundant and characteristic fossil of the Middle Cambrian of the Atlantic province. Its place is wholly taken by *Olenoides* and related forms of trilobites. This may be explained only by assuming effective and constant barriers between these provinces, these barriers being Appalachia on the one hand and the Central European-African land mass on the other. The Middle Cambrian seas of this province entered both the Cordilleran and the

FIG. 1039. — A wonderfully well-preserved Middle Cambrian branchiopod crustacean *Burgesia bella* Walcott, × 3, dorsal view, showing the internal structure through the thin carapace. *st*, stomach; *i*, intestinal canal; *kd*, hepatic cæca; *cl*, connection between hepatic cæca and alimentary canal; *thl*, thoracic legs; *ab*, abdominal region — segmentation not preserved. Middle Cambrian (Burgess shale), British Columbia. (After Walcott.)

FIG. 1040.—*Amiskwia sagittiformis* Walcott. Flattened specimen of a Middle Cambrian worm on shale, × 3. Burgess shale, British Columbia. (After Walcott.)

Appalachian troughs of North America and transgressed over the adjoining lands. They covered parts of China and perhaps other parts of Asia as well.

The best developed sections so far known are in the Cordilleran trough of western America, where, in Alberta, Canada, a thickness of 8300 feet has been measured.[1] These rocks are mostly limestones,

[1] The name Albertan has been proposed by the author for the Middle Cambrian of the Pacific Province. — *Geology of the Non-Metallic Mineral Deposits other than Silicates*, Vol. II, Chapter II, 1920.

but they include some beds of shale, one of which has furnished a remarkable fauna of crustaceans, worms, holothurians, and other organisms, in a wonderful state of preservation, so that in many cases the soft internal anatomy may be readily seen in great detail (Figs. 1039–1041). The extensive limestone development means, of course, a long period of time in deposition and shows further that little clastic sediment was carried into this part of the trough. Because the fauna of this series appears to be so different from that of the Lower Cambrian, it has been thought that here, too, there was a period of complete withdrawal of the waters at the end of the Lower Cambrian and an interval during which the new fauna developed from the old, after which the sea again entered these troughs. No evidence of erosion has, however, been discovered so far at the contact of the Lower and Middle Cambrian beds, and this striking difference of fauna can be explained in another way. As we have seen, the Lower Cambrian *Olenellus* fauna entered the troughs with the waters which spread from the south. During this time there may have been another and different Lower Cambrian fauna in northern waters, which, because of special conditions, developed more rapidly until it had given rise to the *Olenoides* fauna at the close of Palæo-Cambrian time. This fauna then invaded the Cordilleran trough from the north and so marks a very abrupt change in organisms. This is quite in harmony with what has repeatedly occurred in later times.

FIG. 1041. — *Worthenella cambria* Walcott. Middle Cambrian worm flattened on shale, × 2. Burgess shale, British Columbia. (After Walcott.)

That the waters of the Middle Cambrian sea continued to transgress, is shown by the overlap of the Middle over the Lower

Cambrian deposits to the east of the main axis of the trough. Thus in Utah, Montana, and elsewhere in northwestern America,

FIG. 1042. — West Face of House Range, Utah, showing Lower and Middle Cambrian formations. The Lower Cambrian includes the Prospect Mountain quartzites (1375 ft.) and Pioche shales and sandstones (125 ft.). The Middle Cambrian consists of limestones, separated by a bed of shale. (After Walcott.)

the first marine Cambrian beds generally belong to the middle division, resting upon the Belt Terrane or the Uinta quartzite series (Fig. 1044). In Oklahoma, too, the overlap is shown, for,

FIG. 1043. — Mt. Stephen, British Columbia, from the north. *a*, Lower Cambrian (Mount Whyte) formation, resting on sandy beds (St. Piran formation). The upper part of the mountain is formed of Middle Cambrian limestones with a shale bed (Spence shale) between them. At *xx* is a famous fossil bed of the Spence shale. The section includes more than 5800 feet. (After Walcott.)

at the Arbuckle Mountains uplift, limestones with late Middle Cambrian fossils follow upon a basal sandstone, which in turn rests directly upon the crystallines.

It has been questioned whether the northern Appalachian trough was ever invaded by the Middle Cambrian sea, but there is some evidence that this was the case. Thus in Vermont (Georgia and Highgate Springs), and in eastern New York, *Olenoides* and related genera have been found, but in many localities, as in the slate belt of Vermont, in western Newfoundland as well as in northwestern Scotland, Lower Ordovician beds follow directly upon the Lower Cambrian with an erosion interval, marked in some cases. From these facts we may conclude that some Middle Cambrian beds, at least, were deposited in the northern part of this trough,

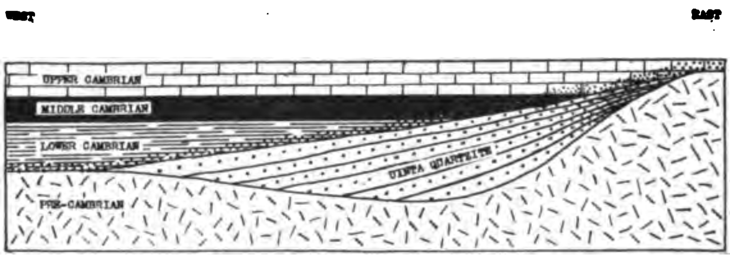


FIG. 1044. — Diagrammatic section to show the relationship of the Cambrian strata to, and their overlaps upon, the late pre-Cambrian continental deposits and the ancient crystallines, along the eastern border of the Palæo-Cordilleran geosyncline in western North America. (Original.)

but that they were worn away again during a long period of exposure in Neo-Cambrian time before the beginning of the late Upper Cambrian transgression of the sea which continued into early Ordovician time.

Turning now to Asia, we find that while Lower Cambrian strata occur in part of the Irkutsk basin, especially in the lower Lena River valley and on the New Siberian Islands, followed there by Middle Cambrian beds, the north Chinese and Korean region is characterized by immense deposits of calcareous beds which carry only the Middle Cambrian fauna. This is the *Olenoides* fauna, many species of which are identical with those found in western America. These beds rest on red sediments, apparently of continental origin, in which is included a remarkable ancient glacial tillite, with scratched pebbles and boulders, similar in appearance to those found in modern glacial tills. This old glacial deposit may represent early Cambrian time, but it belongs most probably to the pre-Cambrian (Figs. 998, 999, pp. 204, 205).

In any case, it is shown that the Middle Cambrian beds widely overlap the Lower Cambrian in the Asiatic region, as they did elsewhere, a fact which emphasizes the transgressive character of the Middle Cambrian sea as far more pronounced than any retreatal movement that may have occurred.

The Upper Cambrian of the Atlantic Province (Bretonian).— The thickest sections of this province representing Upper Cambrian deposits are found in Cape Breton and in the New Brunswick regions, and for this reason the term *Bretonian* is applied to this division. Other sections are found in Wales and England and in Norway and Sweden. The characteristic index fossil of this division is the trilobite *Olenus* (Fig. 1030), which is represented by several species and subgenera in successive horizons. The small trilobite *Agnostus pisiformis* (Fig. 1020) is also abundant in the lower divisions. In early Neo-Cambrian time the Atlantic was still distinct from the Pacific province, but by the close of this period a junction of the two provinces appears to have been effected, as will be shown presently.

In the east Canadian region, the upper Middle and the lower Upper Cambrian beds are sandstones and these are preceded and followed by shales. This indicates shoaling of the sea, followed by deepening in the region where these sections occur. Whether actual emergence took place there is not known at present. That such actual emergence occurred elsewhere toward the end of the Middle Cambrian is, however, well shown in other parts of the Atlantic province, especially in Baltic Russia and in Bohemia, for in neither of these localities is there any Upper Cambrian, except the so-called transition bed to the Ordovician. In Bohemia it rests upon the eroded surface of the Middle Cambrian, but in Baltic Russia it lies upon the Lower Cambrian, and this relationship, as we have explained, was probably due to the erosion of the Middle Cambrian strata in this region. In Wales the Upper Cambrian consists of sandstones (*Lingula flags*), followed by the transition shales (*Tremadoc*), but in some parts of England (Shropshire) the Upper Cambrian beds are absent, the transition series (Tremadoc) beds resting upon the Middle Cambrian as in Bohemia.

There is thus clear evidence over wide areas that the sea withdrew at the end of Meso-Cambrian time and did not return until the close of the Cambrian, when the transition beds, the so-called

FIG. 1045. — Palæogeographic map, to show the distribution of land and sea (black) at the end of late Cambrian or the beginning of early Ordovician time (*Dictyonema–Ceratopyge* period). (Original.)

Tremadoc division (often made the base of the Ordovician) were deposited (Fig. 1045). It was apparently during this interval that the Middle Cambrian beds were eroded from Baltic Russia. The

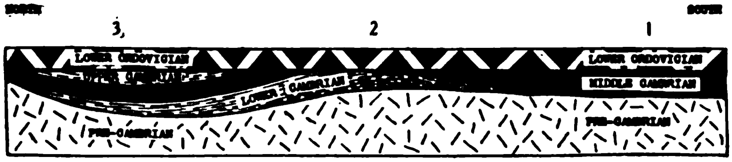


FIG. 1046. — North and south section to show the relationship of the Cambrian to the pre-Cambrian and early Ordovician formations. 1. Bohemian basin; 2. Baltic Russia; 3. Southern Sweden. (Original.)

great transgression at the close of the Cambrian, which resulted in the deposition of the transition or Tremadoc beds upon the various erosion surfaces of the Cambrian rocks (Lower Cambrian in Baltic Russia, Middle Cambrian in Bohemia and parts of Eng-

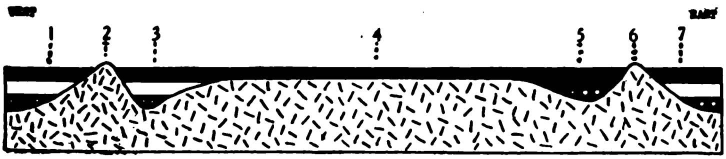


FIG. 1047. — Ideal section across North America, approximately along the fortieth parallel, to show the relationships of the Lower, Middle, and Upper Cambrian formations (modified, after Walcott). 1. Pacific region; 2. Cascadia; 3. Palæocordilleran geosyncline; 4. Canadian platform; 5. Appalachian geosyncline; 6. Appalachia; 7. Atlantic region. Note that the Middle Cambrian is practically wanting in the northern Appalachian geosyncline, while only Upper Cambrian beds occur over the Canadian platform. (Original.)

land, early Upper Cambrian in Sweden), extended also over a much wider area, so that in parts of Sweden and elsewhere in Europe, the Tremadoc beds, which are there called more often

FIG. 1048. — Potsdam sandstone, Gorge of Chateaugay River, near Chateaugay, St. Lawrence County, N. Y. The hard quartzite forms vertical cliffs, because of the pronounced jointing, and the great resistance to weathering. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

the *Ceratopyge* beds, named from a characteristic trilobite (Fig. 1055), overlap the Cambrian strata and rest directly upon the crystallines as the first Palæozoic bed of the region (Fig. 1046).

Upper Cambrian of the Pacific Province (Croixian). — This was characterized by the trilobite *Dicellocephalus* (Fig. 1029) and some other types which are wide-spread in the deposits of this period and province. The greatest known development of the sediments appears to be in the region of the southern Appalachians, the Arbuckle Mountains, and the Cordilleran trough, the thickness in

FIG. 1049. — Potsdam sandstone in Gorge of Chateaugay River, near Chateaugay, St. Lawrence County, N. Y. The quartzite here is thin-bedded, and contains layers which weather more readily. The fall is produced by a harder bed. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

these localities ranging from 3000 to 4000 feet, most of the material being limestone. It is not known at present whether there is a break between the Middle and Upper Cambrian sediments in these regions, but the probability of its existence is great, for the evidence of the withdrawal before the close of Meso-Cambrian time of the sea from much of the area which it covered is almost as clear as it is in the Atlantic province. It was at that time that the erosion took place which removed most or all of the Middle Cambrian in the northern Appalachian trough.

The transgression inaugurated in Neo-Cambrian time was the greatest of the period, for then, for the first time, the sea spread over the interior of the United States as far north as the Canadian boundary. Over all this region Upper Cambrian strata rest directly upon the pre-Cambrian formations, and over most of this area they represent merely the reworked residual sand which covered the old crystallines. (Fig. 1047.) This basal sandstone

FIG. 1050. — Potsdam sandstone in Ausable Chasm. Grand Flume from Rapids down. The regular bedded hard quartzite resists weathering to a pronounced degree, hence the walls of the gorge are vertical. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

of Upper Cambrian age has been called the *Potsdam sandstone*, from a locality north of the Adirondacks in New York (Figs. 1048–1050). In Wisconsin and Minnesota it has been named the *St. Croix* formation, from which the name *Croixian*, now often employed for the deposits as a whole, has been derived (Figs. 982–984, p. 185).

In the Grand Cañon region, it is called the ***Tonto sandstone*** (Fig. 1051, and section, Fig. 988, p. 190). Another name that has been used is *Saratogan*, from Saratoga, N. Y. Besides the

FIG. 1051. — Cliffs of sandstones of the Tonto Group in cañon, four miles north of Peach Springs, Arizona. Grand Cañon Cliffs in distance. (U. S. G. S.)

diagnostic trilobite *Dicellocephalus*, the brachiopods *Obolella* (*Dicellomus*) *polita* (Fig. 1014 *a*) and *Lingulepis acuminata* (Figs. 1014 *b*, *c*) are characteristic of it.

The Closing Period of the Cambrian

Throughout both the Atlantic and the Pacific provinces, the transgression inaugurated late in Neo-Cambrian time continued

FIG. 1052. — West face of Notch Peak, House Range, Utah. The cliffs show the Upper Cambrian (Notch Peak) limestones 1400 feet thick, capped by Ordovician limestone. (After Walcott.)

without interruption into the Ordovician, so that, in many sections which the transgression did not reach at the end of Cambrian time, Lower Ordovician beds rest directly upon the older rocks (whether

FIG. 1053. — Cambro-Ordovician limestone of China, T'ai shan-ho, Province of Shan-si, China. (After Willis, from Walcott.)

earlier Cambrian or pre-Cambrian). As another result of this continued transgression, a transition series was formed between the Cambrian and the Ordovician (Figs. 1052, 1053), in which the surviving Cambrian types were commingled with the earliest Ordovician types. In the Atlantic province, this constitutes the Tremadoc series of shales, a portion of which was characterized by the graptolite *Dictyonema flabelliforme* (Fig. 1054). In North America beds of this type have been called *Ozarkian* by Ulrich. In the Siberian region these are referred to as the *Ceratopyge horizon* from a characteristic trilobite *Ceratopyge forficula* (Fig. 1055).

It was during this period of pronounced transgression that the barriers between the provinces were partly broken down. The

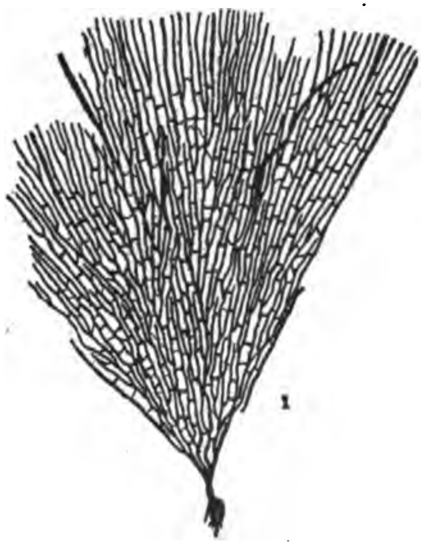


FIG. 1054. — *Dictyonema flabelliforme.* A characteristic graptolite of the Cambro-Ordovician transition shales of Europe and North America.

FIG. 1055. — *Ceratopyge forficula.* A characteristic trilobite of the Cambro-Ordovician transition limestones of Europe. Cephalon (*a*) and pygidium (*b*).

Atlantic invaded the northern Appalachian trough somewhere in the St. Lawrence region, as is clearly shown by the fact that shales with *Dictyonema flabelliforme* are found in the Albany region of eastern New York. The Siberian sea also became confluent with the Baltic embayment, as is shown by the intermingling of the *Ceratopyge* and *Dictyonema* (Tremadoc) faunas (Fig. 1045).

The Cambrian of India

The remarkable case of the Indian Cambrian may be briefly referred to. In northwest India, in the so-called Salt Range, Cambrian beds, with a fauna quite distinct from any known in the other provinces, rest upon red sandstones and shales which contain a great bed of rock-salt from which the range takes its name. From their position it would appear as if the rock-salt deposit is of early Cambrian or of pre-Cambrian age, and therefore the oldest upon the earth. More recently it has been suggested, however, that this rock-salt and the enclosing beds are of Tertiary age and that the Cambrian beds overlie them as the result of a great overthrust or possibly an overturn fold. This appears to be the true relationship.

CHAPTER XXXIII

THE ORDOVICIAN OR ORDOVICIC SYSTEM

This system, like the preceding, is a subdivision of the old greywacke series of Wales, representing essentially the middle portion of that complex. The rocks which belong to it in northern Wales, the type locality, were at first classed by Sedgwick as a part of the Middle and the whole of the Upper Cambrian, but rocks which contained similar fossils in South Wales, and clearly of the same geological age, were made by Murchison the type of his Lower Silurian. Partly because of Murchison's official position as the director of the Geological Survey of Great Britain, and partly because of the general adoption of his term by Continental geologists, this system was for a long time known as the Lower Silurian, and in most European and American writings of the period preceding the last two decades, and upon all the older geological maps, this second system of the Palæozoic is thus designated. The followers of Sedgwick, however, continued to refer the rocks in question to the Upper Cambrian, and it was only sometime after the proposal of the term Ordovician for this system, by Professor Lapworth (1879), that geologists generally came to the agreement that this new term satisfied the requirements of exact nomenclature. The name itself was derived, as previously noted, from that of the ancient Celtic tribe of Ordovices which at the time of the Roman conquest occupied the territory now included in northeast Wales and adjoining parts of England (Shropshire), that is, the region where the rocks of the middle division form rugged peaks which in some cases rise to heights of nearly three thousand feet. (See map, Fig. 742, p. 12.)

Like the Cambrian, the Ordovician rocks of Wales are strongly folded and much broken, while igneous intrusions and ancient lava sheets are especially numerous. In general, sandstones and grits are most characteristic of the lower, shales of the middle, and shales and limestones of the upper part. At certain horizons, the shales include many graptolites, while the limestones contain brachiopods and other characteristic fossils.

Rocks of this period again form high peaks in the Lake district of Cumberland (northwest England; see map, Fig. 639, p. 745, Pt. I), and here too igneous rocks constitute a large part of the series. Finally, the disturbed rocks of southern Scotland belong largely to this system, they being commonly graptolite-bearing shales. In northwest Scotland, on the other hand, the rocks of this age are wholly calcareous (*Durness limestone*).

Graptolite shales also constitute an important lithic type of the rocks of this system in Sweden, but limestones, largely filled with trilobite and cephalopod remains (*Orthoceras limestone*, etc.), alternate with the shales and become the dominant type of rock farther east in Russia.

One of the most complete and best-known series of formations representing this system occurs in the Bohemian basin, where these rocks are richly fossiliferous, constituting the second system in the subdivision of the Bohemian Palæozoic series as developed by Barrande. They have been so thoroughly studied, and their fossils so fully described, that they are generally considered the most typical representative of the Ordovician system of Europe. Ordovician rocks are also exposed in many other districts of Europe, but they have for the most part been subject to much disturbance, and their fossils are not, as a rule, well preserved.

A vast area in northern Siberia is covered by rocks of this system, and some of these include important beds of rock-salt. Very little is, however, known of them.

Probably no other region in the world retains these ancient rocks in such completeness and with so little alteration, as does North America, especially the eastern half (Fig. 1056). Many members of the series are highly fossiliferous, and the fossils are often beautifully preserved. They were first studied in the greatest detail in the state of New York, where, as over much of the interior, they are nearly horizontal and abound in organic remains. Hence the standard subdivision of these rocks is based on the New York series, and the current names of the formations are derived from New York localities. Other important American localities are: the Province of Ontario, the upper Mississippi Valley region, the Cincinnati Dome, and the Appalachian Mountains. In the southern Appalachians, the rocks have suffered a certain amount of folding, though this is only locally intense, but in the northward extension of this ancient mountain system, where these rocks are more often shales and sandstones, the disturbance was generally very profound, so that where they are now exposed, as in the

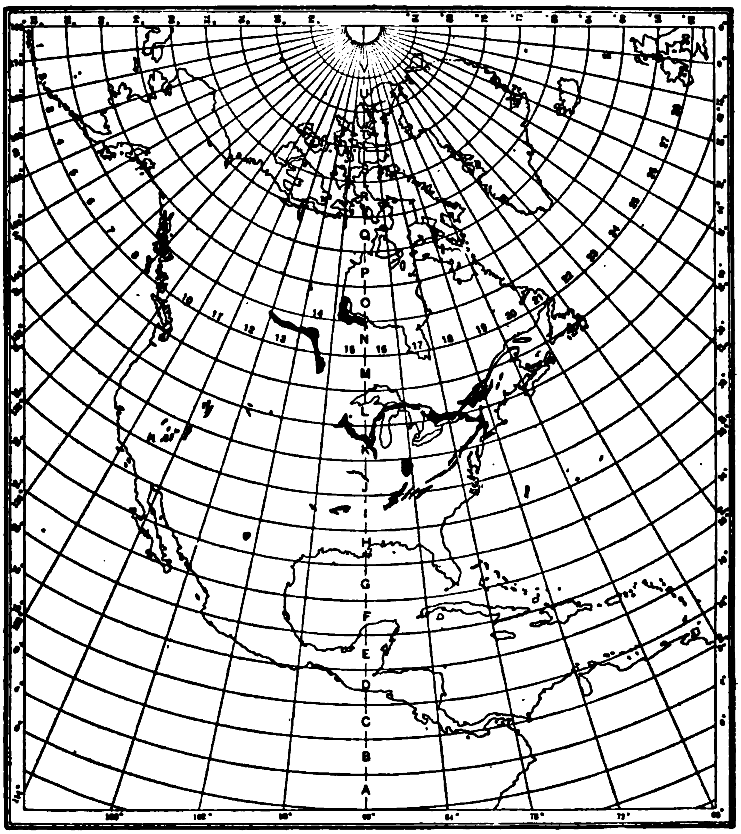


FIG. 1056. — Map of North America showing the outcrops of the Middle and Upper Ordovician rocks. (After Bailey Willis.)

banks of the upper Hudson River, and in the slate belt country of New York and Vermont, they are very similar in appearance to the old greywackes of Wales.

In the Rocky Mountains also, extensive limestones and other rocks belonging to this system are found, and they have been traced into Arctic America. Nor are they unknown in the southern hemisphere both in the Old and the New World, though on the whole these southern phases are less well known.

General Relations to Preceding Formations

As we have seen, the great marine transgression which began in late Cambrian time continued into the early Ordovician, as a result of which the strata of the latter period overlap the Cambrian in a number of localities and rest directly, and usually with a basal sandstone, upon the pre-Cambrian rocks. Where they succeed the Upper Cambrian beds, they follow them conformably and grade downward into them. In a number of cases, however, where Lower or Middle Cambrian strata were exposed to erosion, these regions were not again covered by the sea until early Ordovician time, so that strata of that age rest directly upon the eroded Middle or Lower Cambrian. Thus the base of the Ordovician has one of the following relationships:

1. Conformably overlying Upper Cambrian.
2. Overlapping the Cambrian and unconformably resting upon the pre-Cambrian.
3. Disconformably overlying Middle or Lower Cambrian.

Subdivisions of the Ordovician

New York State Series of Formations. — Although the Ordovician system was originally described from Wales and the adjoining districts of western England, the most complete series of subdivisions is found in North America. The formations were here first studied by Ebenezer Emmons (portrait, Fig. 1006, p. 220) geologist of the second New York district, who grouped them together as the Champlain System from the extensive exposures of these beds around the border of that lake. East of Lake Champlain, in Vermont, and in the Taconic range of mountains which forms the boundary line between New York and Massachusetts, the rocks are strongly folded and partly metamorphosed. These, as we have seen, Emmons regarded as belonging to an older system which he called the Taconic system and which he considered to be essentially the equivalent of the Cambrian system of Sedgwick. In this he was correct so far as a part of his system is concerned, but besides this there are infolded and faulted strata of Ordovician age, to which system the whole series was referred by most

American geologists of Emmons' time. The discussion of the age of these folded and metamorphosed rocks has come to be known as the "Taconic controversy."

The Ordovician system is, however, incomplete in the Champlain valley, but a nearly complete succession is obtained by combining the various sections around the borders of the Adirondacks. This gives us the following succession of formations in descending order for New York.

Upper Ordovician or Cincinnatian (including Trenton)	9. Queenston shale
	8. Oswego sandstone
	7. Lorraine (Pulaski) shales and sandstones
	6. Frankfort shales
	5. Utica shales
	4. Trenton limestone
Middle Ordovician or Champlainian	3. Black River limestones
	2. Lowville-Chazy limestones
Lower Ordovician or Canadian	1. Beekmantown group

Characteristic Sections

In order that the student may gain a clear conception of the relationships of the strata at the present time, a number of characteristic cross-sections are introduced.

Lake Champlain Section (Fig. 1057). — If we start in the Adirondack Mountains west of Lake Champlain, and go eastward,

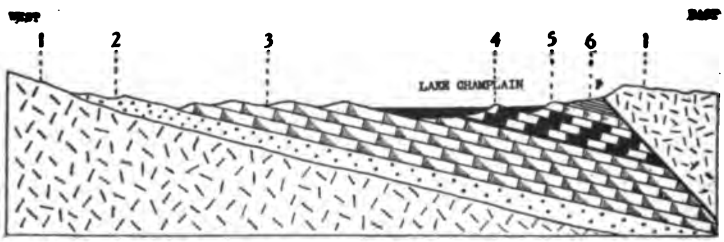


Fig. 1057. — Section from the Adirondacks across Lake Champlain, showing the relationships of the formations (vertical scale and dip of strata greatly exaggerated). 1, Pre-Cambrian crystallines; 2, Potsdam sandstone; 3, Beekmantown limestone; 4, Chazy limestone; 5, Trenton limestone; 6, Utica shale; F, fault. (Original.)

we pass abruptly from the crystallines to the Potsdam sandstone which dips here to the east. Walking across the outcrop, we find that the upper beds become more calcareous, forming the Calciferous Sandrock of the older geologists, and this gradually becomes less sandy until it passes into a rather pure magnesian limestone. Because of its fine exposure in Beekmantown township

FIG. 1058. — *Cryptozoön proliferum* Hall. Glaciated surface of *Cryptozoön* reef bed of Hoyt limestone, northwest of Saratoga, N. Y. Erosion here has produced natural sections of these masses showing the concentric structure. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

on the Lake; this limestone is now called by that name. It forms the western shore of Lake Champlain at many points, and its total thickness, as measured in that region, is about 1800 feet. In its lower part fossils are rare, except the calcareous alga *Crypto-*

FIG. 1059. — *Ophileta compacta.* A characteristic gastropod of the Beekmantown of the Champlain region. Opposite views and section.

zoön (Fig. 1058) and the flat coiled gastropod *Ophileta compacta* (Fig. 1059). Its upper beds, however, also called the Fort Cassin division, contain many fossils, among which we may mention the loose-coiled gastropod *Eccilioplerus* (Fig. 1060), the trilobite *Asaphus* (*Isoteloides*) *whitfieldi* (Fig. 1061), and large cephalopods of the *Endoceras* type (Fig. 1138 *f*) as well as coiled forms.

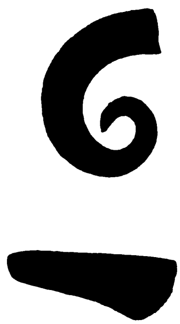


FIG. 1060. — *Eccilioplerus triangulus*. Top and side views. Characteristic gastropod of Beekmantown; Champlain region.

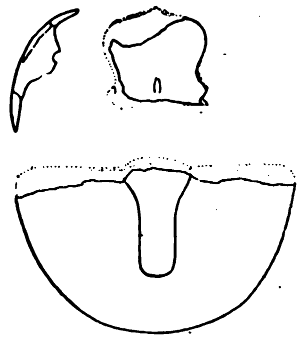


FIG. 1061. — *Asaphus* (*Isoteloides*) *whitfieldi*, a characteristic trilobite of the Beekmantown of the Champlain region; pygidium, part of cephalon and a free cheek. (I. F.)

Crossing into Vermont where the lake is narrow, we find the top of the formation marked by an erosion surface with a bed of sand or pebbles separating it from the overlying Chazy limestone.

FIG. 1062. — Cliff of Chazy limestone, Valcour Island, Lake Champlain. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

This limestone is commonly fine-grained, producing the so-called black marble of Isle La Motte, formerly much used in the flooring of public buildings (Fig. 1062). The maximum thickness of this formation here is about 900 feet, and different divisions of it are characterized by different fossils, such as the brachiopod *Orthis costalis* (Fig. 1063), the left-handedly coiled gastropod *Maclurea magna* (Fig. 1064) and the small plicated rhynchonelloid brachiopod *Camarotœchia plena* (Fig. 1065). It is followed by thin-bedded, often somewhat bituminous limestones, the Black River-Trenton series with many fossils, including brachiopods of the *Orthis* group (*Dalmanella testudinaria*, Fig. 1066 *a–c*, *Platystrophia*, Fig. 1066 *d*, *e*), of the strophomenoid group (*Plectambonites sericeus*, Fig. 1066 *f–h*, and others), also by pelecypods, gastropods and cephalopods

FIG. 1063. — *Orthis costalis*, a characteristic lower Chazy brachiopod, and section of same.

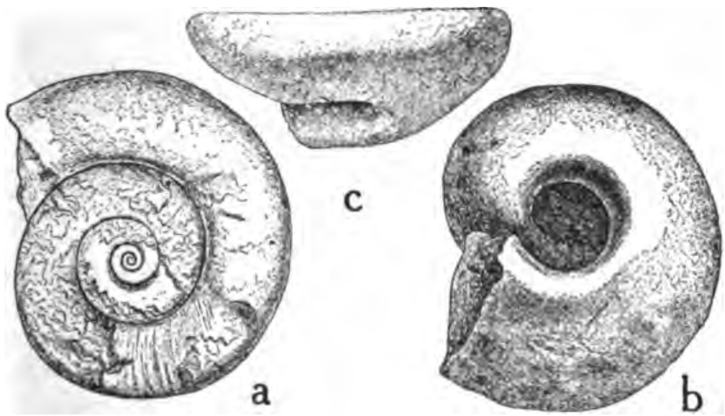


FIG. 1064. — *Maclurea* (*Maclurites*) *magna*. A characteristic middle Chazy gastropod. Top, side, and bottom views.

(orthoceran types) and trilobites, especially the ornamental *Trinucleus* (Fig. 1067) and the large *Isoteles gigas* (Fig. 1068) with a cephalon and pygidium of the same size. After about 300 feet of this limestone, there follows a series of black bituminous shales known as the *Utica* shale in which the trilobite *Triarthrus becki* (Fig. 923, p. 143) and graptolites (*Diplograptus*, *Climacograptus*, Figs. 1100 *a*, *b*, etc.) are found. After about 600 feet of these shales the section is cut off by a fault.

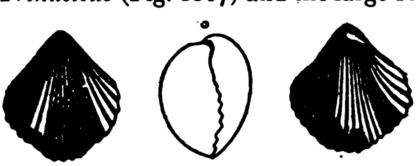


FIG. 1065. — *Camarotœchia plena*. A characteristic upper Chazy brachiopod; 3 views.

Analysis of the Section. — In this section the student should note the following: (1) Continuous deposition is indicated from the base of the Potsdam sandstone (Upper Cambrian) through

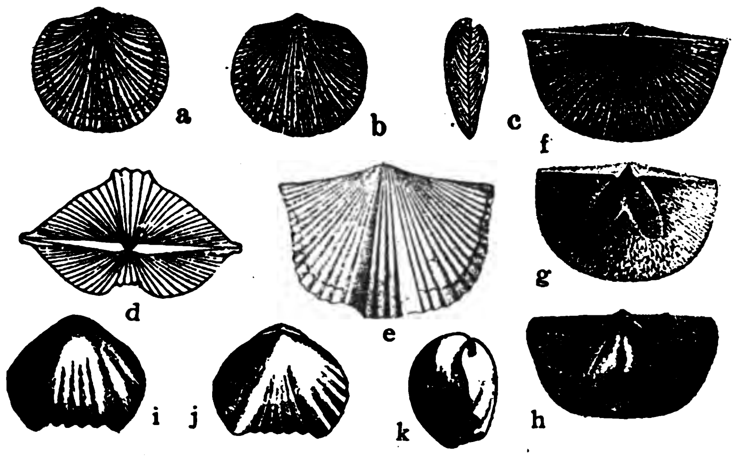


FIG. 1066. — Characteristic Trenton brachiopods. *a–c*, *Orthis (Dalmanella) testudinaria*, 3 views; *d*, *e*, *Platystrophia*, 2 views, enlarged; *f–h*, *Plectambonites sericeus*, 3 views (2 of interior), enlarged; *i–k*, *Parastrophia hemiplicata*, 3 views.

1800 feet of Beekmantown limestone, which begins with impure sandy and unfossiliferous beds and ends with pure fossiliferous limestones. This succession indicates continuous transgression of the sea in which these beds were deposited, the locality becoming more and more distant from the shore, permitting purer limestones to accumulate. In other words, the shore was steadily moving away, in this case toward the Adirondacks, so that if the rocks since worn away could be restored, we should find that the Beekmantown beds formerly reached a considerable distance up the flanks of these mountains (Fig. 1069). This implies, of course, that they once overlapped the Potsdam beds and rested directly upon the crystallines, a condition still seen at Little Falls south of the Adirondacks.

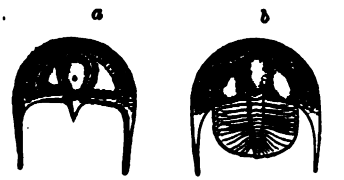


FIG. 1067. — *Trinucleus concentricus.* A characteristic Trenton trilobite. North American. Cephalon, and entire specimen.

(2) We next note the disconformable contact between the Chazy and the Beekmantown, marked by an erosion plane and a basal

sandstone in the Chazy series. This indicates a withdrawal of the sea toward the end of Beekmantown time and a return in Chazy time. As we shall see later, this withdrawal affected a wide area and marked an important event in the Ordovician. After the return of the sea, so far as our section indicates, deposition was continuous, the waters becoming purer and richer in organisms. The fact that with the beginning of Black River-Trenton deposition many new organisms appeared, can be explained as the result of the opening of passageways which connected these waters with the regions where the new forms were developing. Finally, however, there came an influx of black bituminous muds and in them were buried only the graptolites and a few other forms.

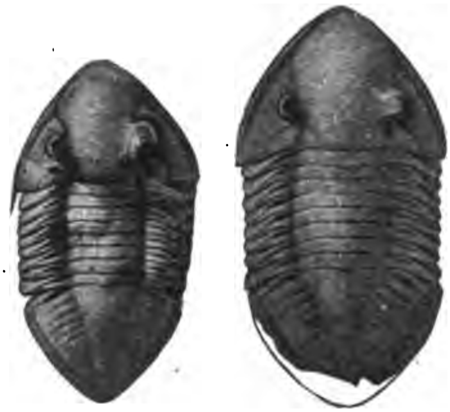


FIG. 1068. — *Isoteles gigas* DeKay. Two forms of this characteristic trilobite of the Trenton. (From Bassler.)

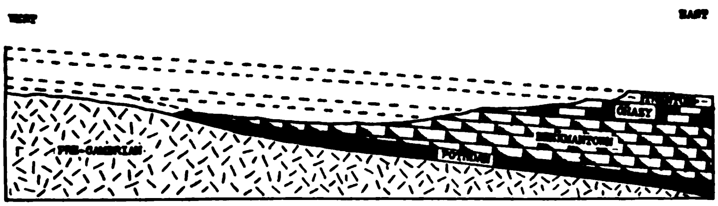


FIG. 1069. — Section showing the former extension of the Beekmantown and higher formations on to and perhaps across the Adirondack Mountains. (Original.)

Comparison with Other Sections. — Let us now consider separately the lower two divisions of this section, the Beekmantown and Chazy, and note their characters elsewhere. Let us keep in mind the break between them and its significance in terms of stratigraphic history.

If we trace these beds northeastward, we find a great thickness of limestones representing both the Beekmantown and the Chazy in western Newfoundland, and in northwest Scotland. In both regions the Beekmantown rests disconformably on Lower Cambrian, and it and the Chazy which succeeds have essentially the fauna found in the Champlain Valley. Evidently these regions belonged to one and the same province in early and mid- Ordovician time. We do not yet know whether in these sections the Beekmantown and Chazy are separated by a disconformity. It may be that these regions lay too far within the basin to be affected by the retreat.

Fig. 1070. — *Phyllograptus typus*, a group of specimens, with cross-section of one restored. Lower Ordovician. (After Hall.)

If we now follow the Beekmantown and Chazy deposits southward in the Champlain-Hudson region, we find that both decrease in thickness. The Beekmantown is thinner because only the lower members are present; the Chazy is thinner because only the upper members are present. In other words, the break between the two series becomes greater as we proceed southward. Thus the more southern regions were affected earlier by the retreat and later by the re-advance than those farther north, which means a withdrawal to the north.

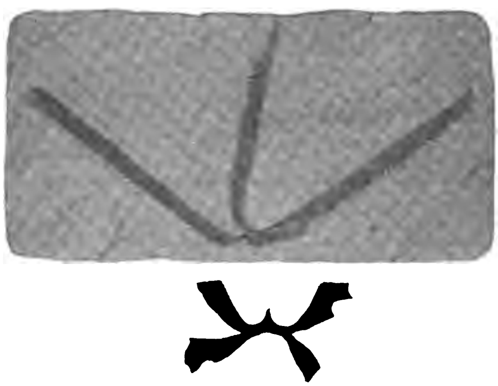


Fig. 1071. — *Tetragraptus bryonoides;* portion of a colony, and an enlargement of the early cells. Lower Ordovician. (After Hall.)

Finally, when we reach the Hudson Valley near Albany, the Beekmantown limestone is replaced by a series of shales and sands

(Deepkill), with characteristic graptolites (*Phyllograptus*, Fig. 1070, *Tetragraptus*, Fig. 1071, *Didymograptus*, Fig. 1072, *Dichograptus*, Fig. 1073). The same is true of the upper Chazy, which is

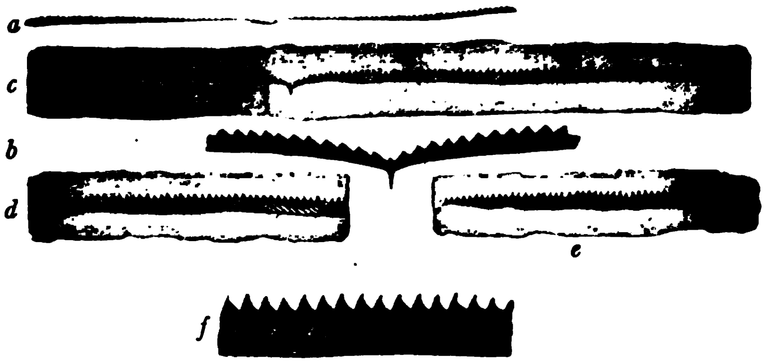


FIG. 1072. — Lower Ordovician graptolites. (*a*, *Didymograptus nitidus*; *b*, enlargement of part of a small individual of the same species; *c*, *D. patulus*; *d*, *e*, portions of stipes enlarged; *f*, part of *e* further enlarged. Deepkill beds (Beekmantownian). (After Hall.)

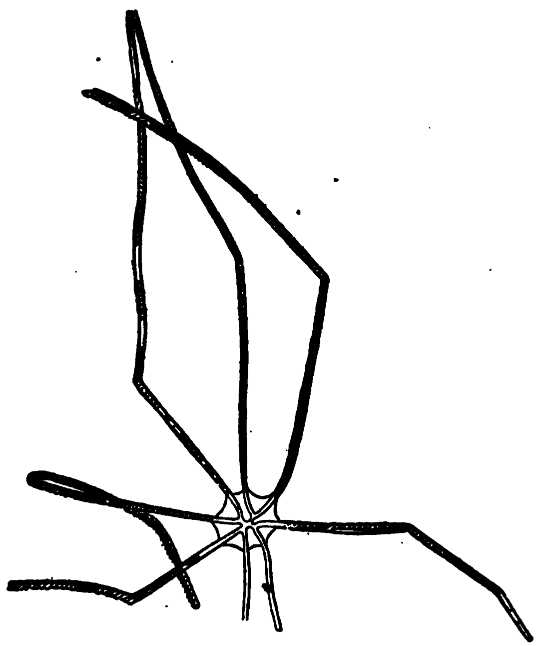


FIG. 1073. — *Dichograptus octobrachiatus*, Beekmantown. (Deepkill). (After Hall.)

here represented by the Normanskill shale, also with characteristic graptolites (*Cœnograptus*, Fig. 840 *D*, p. 99, *Climacograptus bicornis*, Fig. 1074 *a*, *Dicellograptus*, Fig. 1075 *a–c*, *Dicranograptus*, Fig. 1074 *b*, *Diplograptus*, Fig. 1076 *a–b*).

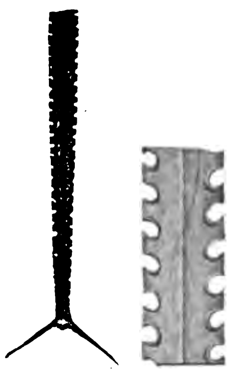


FIG. 1074 *a*. — *Climacograptus bicornis*. A typical Middle Ordovician graptolite, specimen × 2, and a portion further enlarged. (After Hall.)

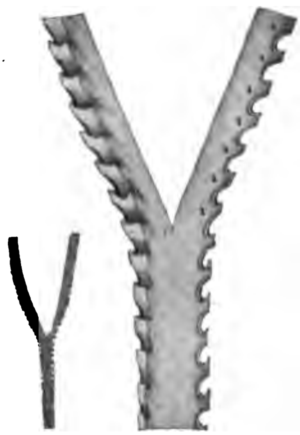


FIG. 1074 *b*. — *Dicranograptus ramosus*. A typical Middle Ordovician graptolite, natural size, and a part enlarged. (After Hall.)

Passing on into the southern Appalachian region, we find an increasing thickness of limestones representing each series, so that in central Pennsylvania there are about 2500 feet of Beekmantown limestones and a similar thickness of Chazy limestones.

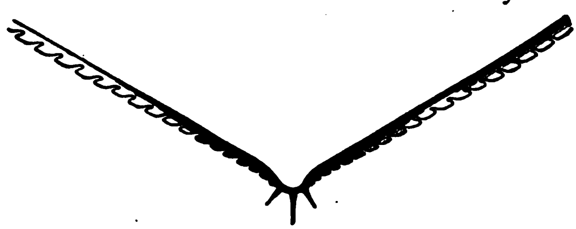
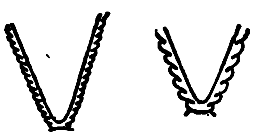


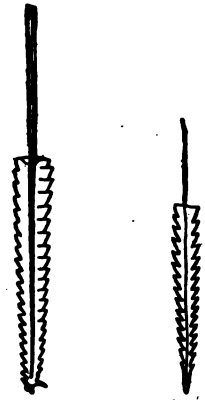
FIG. 1075 *a*. — *Dicellograptus divaricatus*, enlarged. A typical Middle Ordovician graptolite. (After Nicholson.)

Still farther south in the Appalachian trough, some 4000 feet of dolomitic limestones (Knox dolomite, including the limestone of the Natural Bridge of Virginia, Fig. 355, p. 426, Pt. I) represent the Beekmantown and Upper Cambrian beds, and another thick series of limestones represents the Chazy. In many places the evidence of the break between the two is still recognizable (Fig. 1077). But the most striking fact about these deposits is that the faunas of both formations often differ decidedly from



b c

FIG. 1075 *b, c.* — *Dicellograptus sextans.* A typical Middle Ordovician graptolite. *b,* Slightly enlarged; *c,* same, base still more enlarged. (Nicholson.)



a b

FIG. 1076. — Middle Ordovician graptolites. *a, Diplograptus foliaceus.* (Normanskill and Llandeilo) America and Europe; *b, Diplograptus acuminatus* (Llandeilo, Europe.) Both enlarged. (After Nicholson.)

FIG. 1077. — Disconformable contact between massive Beekmantown at the base, and thin bedded upper Chazy (Frederick) limestone. Near Frederick, Maryland. (After Bassler.)

those found in the equivalent formations in the Champlain basin, though similar forms also occur. In the lower division fossils are

FIG. 1078. — *Orthis wemplii*, a characteristic lower Beekmantown brachiopod of the southern phase. (This shows characters intermediate between true *Orthis* and *Dalmanella*.) (After Bassler.)

FIG. 1079. — *Ophileta levata*, a characteristic gastropod of the lower Beekmantown, southern phase.

FIG. 1080. — *Turritoma acrea*. A characteristic Beekmantown gastropod. Newfoundland and southern states.

generally rare and of small form (ostracods, small brachiopods, gastropods, etc., Figs. 1078–1081). In many sections the calcareous alga *Cryptozoön* is a characteristic fossil of the lower beds (Fig.

FIG. 1081. — *Ceratopea keithi*, Ulrich. Opposite views of four specimens of a Beekmantown gastropod of the southern phase. (After Bassler.)

1058, p. 261). The rocks are often thin-bedded, forming "ribbon limestones," while beds of sand and so-called "edgewise conglomerates" (Fig. 1082) are frequent, indicating deposition in shallow waters. The organisms were probably derived from the Pacific, and their restriction in size and variety suggests unfavorable, possibly cool, conditions.

FIG. 1082. — Edgewise conglomerate, Beekmantown formation, Hagerstown Valley, Maryland. (After Bassler.)

The succeeding formation of Chazy age also contains a very different fauna, especially in the lower part, though in the higher member the characteristic Champlain species are found. In the southern Appalachians, where it rests disconformably upon the Knox,[1] it is called the Chickamauga limestone, although this series also contains higher formations; elsewhere the name Stones River group is given to it.

This difference in the faunas suggests at once that the graptolite-bearing mud deposits of the Albany region formed, for a time at

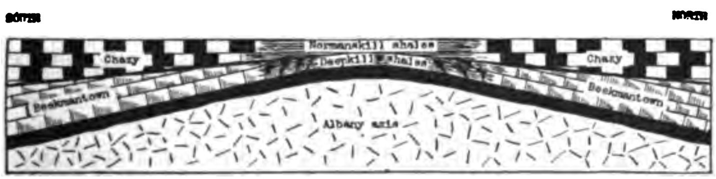


FIG. 1083. — North-south section in the Appalachian trough to show the barrier formed by the Deepkill shales (delta type of deposit) between the northern and southern Beekmantown seas, and by the Normanskill shales and sandstones (also a delta deposit) between the northern typical Chazy and the southern Stones River type of Chazy. These barriers explain in part the differences of the northern and southern types of faunas. The shales themselves carry chiefly graptolites. (Original.)

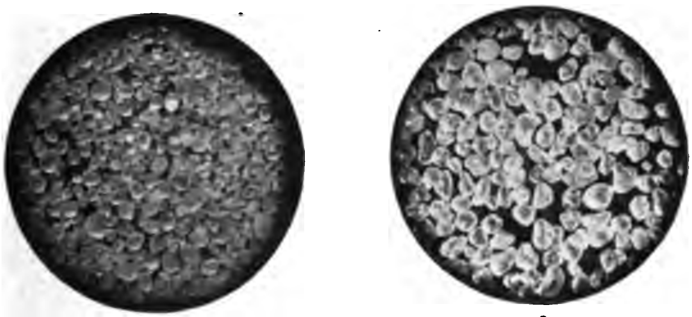
[1] The names Knox and Chickamauga are here used in the general sense in which they are employed in the folios of the Geological map of the U. S. G. S.

least, a barrier between the northern (Champlain-Newfoundland-N. W. Scotland) section of the Appalachian trough and the southern one, and from the character of that rock and its distribution, we conclude that it represents muds washed in from Appalachia on the east and built, more or less in the form of a delta, into the sea which occupied the trough. Furthermore, because the beds are thinnest here, and the break between the two members most profound, we conclude that this region emerged first, the waters re-

FIG. 1084. — Disconformable contact of thin-bedded lower Trenton limestone upon eroded surface of massive upper Beekmantown (Tribes Hill) dolomite in the gorge of Canajoharie Creek, New York. (For shale overlying the Trenton limestone in this gorge, see Fig. 1108.) (Courtesy N. Y. State Museum, John M. Clarke, Director.)

treating northeastward in the Champlain, and southward in the southern, portion of the trough, and further, that this same district was the region last submerged in the readvance (Fig. 1083). In some cases the Chazy is absent altogether, the Black River or early Trenton beds resting disconformably on the lower Beekmantown beds (Little Falls dolomite) or upon the upper Beekmantown (Fig. 1084).

Over the greater part of North America east of the Rockies we find the same pronounced break between the Beekmantown and Chazy formations (here generally called Lower Magnesian limestone and Stones River group, respectively). Over a large part of the area the horizon of the disconformity is occupied by a pure quartz sandstone, the St. Peter, which ranges in thickness up to 200 feet. This sandstone is so pure, its grains are so well rounded and assorted according to size (Fig. 1085 *a*, *b*), that we are led to the conclusion that it represents a series of dunes shifted about by the winds while the continent was emerging during the retreat of the sea southward and eastward. These sands successively covered the emerging Beekmantown deposits as they became exposed, and thus, while they rest upon lower Beekmantown where the emergence took place early in the retreat (Minnesota, Wisconsin, Mohawk valley), they rest necessarily upon younger Beekmantown beds, and there-



a *b*

FIG. 1085 *a*, *b*. — Micro-photographs of St. Peter sand grains, enlarged about 11 times. *a*, from Missouri; *b*, from Minneapolis, Minnesota. The grains are well rounded and of uniform size, but differ in size in the two localities. (W. H. Sherzer photo; from Grabau and Sherzer, *Monroe Formation of Michigan*.)

fore upon a greater thickness of the formation as a whole, farther south. Thus, while in the northern regions mentioned, the thickness of the Beekmantown below the St. Peter sandstone varies from about 200 or less to 400 feet, its thickness in central Pennsylvania and in Oklahoma, where it is also covered by the sandstone or its equivalent, is about 2500 feet. Again, while the Chazy strata overlying the St. Peter are over a thousand feet thick in the southern region, they are often less than a hundred feet in Minnesota and in the Mohawk Valley of New York (there called Lowville group). The following sections represent these conditions from north to south (Fig. 1086).

In the Rocky Mountain region a similar sandstone occurs at this horizon (Hardiston sandstone), and it carries the oldest fish remains so far known. The remains were apparently washed from the land-waters with the sands as the sea retreated. The fish probably lived in the rivers which supplied this sand. Similar though more complex conditions also existed west of the Rocky Mountain region in the Cordilleran geosyncline.

It is now clear that the great transgressive advance of the sea which began in Upper Cambrian time and continued into the Lower

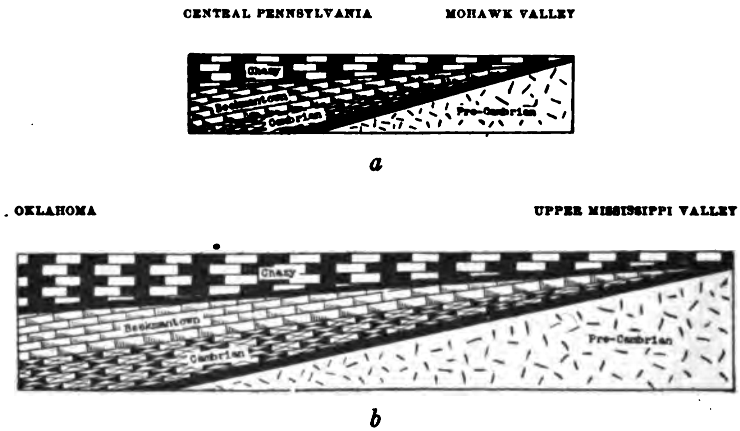


FIG. 1086. — *a*, Section from the Mohawk Valley to Central Pennsylvania showing the overlapping Cambrian strata at the base (with the basal sandstone in black) rising progressively in the series, the offlapping Beekmantown beds formed during the retreat of the sea, and the succeeding overlapping Chazy beds. Note that in the Mohawk Valley late Chazy (Lowville) or early Trenton lies on lower Beekmantown (see also Fig. 1084) or overlaps it resting directly upon the basal sandstone. *b*, Similar section from the upper Mississippi Valley to Oklahoma. The section here corresponds to *a* except that the *hiatus* between the Beekmantown and Chazy is occupied by the St. Peter sandstone (also shown in black). (Original.)

Ordovician (Fig. 1087) was followed by an equally great retreat until much of the North American continent, except the deeper parts of the geosynclinal troughs, had again become dry land, much of it being covered by sands which were moved about and built into dunes by the wind (Fig. 1088). The end of this emergence is the end of Beekmantown or Lower Ordovician time. Then followed a reëmergence during Chazy or Middle Ordovician time, and the St. Peter sands were reworked by the sea into a basal bed (Fig. 1089). This second transgression continued into Trenton time (Fig. 1090), and as we have seen, in some cases the Trenton

FIG. 1087. — Palæographic map of North America showing the greatest advance of the sea shortly after the opening of Palæo-Ordovician time (Beekmantown). Seas in black. (Original.)

beds are the first to rest upon the erosion surface of the lower or upper Beekmantown (Fig. 1084, p. 272).

In several parts of the Appalachian trough, as at Albany and at Point Lévis, opposite Quebec, as well as in Arkansas and even

FIG. 1088. — Palæogeographic map of North America showing the extent of the greatest retreat of the sea at the end of Palæo-Ordovician (Beekmantown) time. Seas in black. (Original.)

in the northern Cordilleran trough, black muds with graptolites, of the types characterizing the Atlantic deposits (Arenig-Llandeilo of Britain, etc.) are found. The muds probably indicate delta formation, but the graptolites suggest that there was a connection

FIG. 1089. — Palæogeographic map of North America showing the outlines of land and sea (black) at the end of Meso-Ordovician (Chazy-Lowville) time. (Original.)

at this time with the Atlantic Ocean. Apparently, however, few other organisms than the pelagic graptolites entered the interior North American waters.

FIG. 1090. — Palæogeographic map of North America showing the greatest advance of the sea (black) in early Neo-Ordovician time. (Trenton epoch.) (Original.)

The Upper Ordovician Formations

In order that the characteristics of the American Upper Ordovician may appear more clearly we will give several additional sections.

Section West of the Adirondacks. — A section extending in a general westerly direction from the Adirondacks gives the following succession of outcrops (Fig. 1091).

FIG. 1091. — Section southwestward from the Adirondacks and Black River to Oswego, New York, showing the relationships and succession of the Ordovician formations. Length of section about forty miles. Compare with section, Fig. 1057, p. 260. (Original.)

The contact line between the sedimentaries and the crystallines of the western Adirondacks is followed for some distance by the Black River. In its bed and banks we find the lowest sediment to be a quartz sandstone which rests directly upon the crystallines,

FIG. 1092. — Quarry section, showing contact (a hat) of lower Black River (Leray) limestone and the upper thin-bedded Lowville (Chazy). Midway in the Lowville is a reef layer of *Stromatocerium*. Three Mile Bay station, Jefferson County, New York. (Photo by H. L. Fairchild. Courtesy N. Y. State Museum, John M. Clarke, Director.)

and is followed by a limestone series about 100 feet thick. On the bedding planes of some of the strata of this limestone are

FIG. 1093. — Fall in the Black River at Watertown, New York. This is the type-locality for the Black River (Watertown) limestone. The river tumbles over the lower cherty member of this rock, into the gorge cut into the Lowville beneath. (E. O. Ulrich, photo. Courtesy N. Y. State Museum, John M. Clarke, Director.)

shown the cross-sections of many vertical tubes filled with calcite, and from the general appearance thus produced, the rock was formerly called *Bird's-eye limestone*. This formation is now known

FIG. 1094. — Black River limestone near river, at Watertown, New York, showing the "seven foot tier" and the upper portion of the cherty bed (seen in the falls, Fig. 1093) beneath. (E. O. Ulrich, photo. Courtesy N. Y. State Museum, John M. Clarke, Director.)

as the *Lowville limestone*, and it is the representative of the upper Chazy, carrying, however, for the most part, the Stones River type of fossils (Fig. 1092). It is succeeded by the ***Black River lime-***

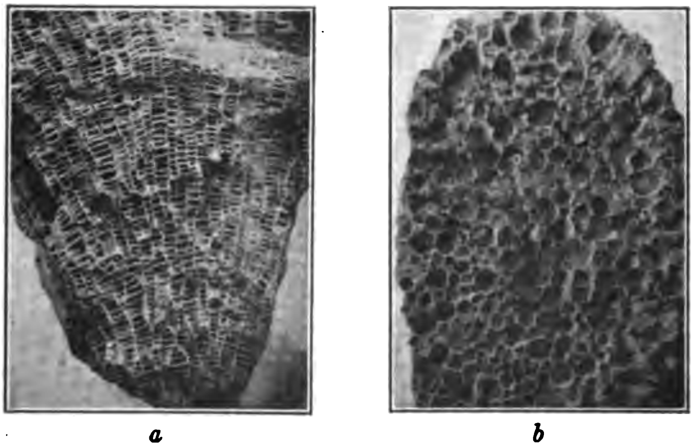


FIG. 1095. — *Columnaria halli*, a characteristic Black River coral. *a*, side view of a broken fragment; *b*, top view. (After Rominger.)

stone (Figs. 1093, 1094) which is especially characterized by coral heads (*Columnaria*, Fig. 1095), consisting of numerous prismatic tubes divided by horizontal plates and with longitudinal ridges on

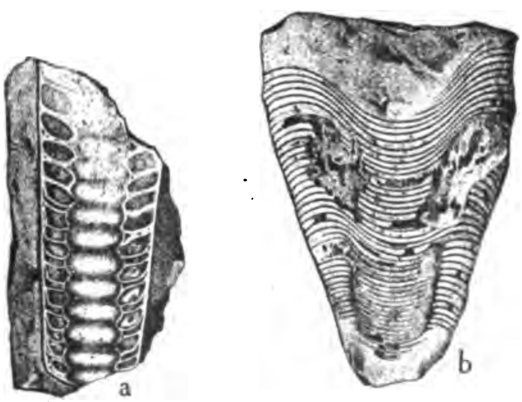


FIG. 1096, *a*, *b*. — Typical cephalopods of the Black River limestone. *a*, *Actinoceras tenuifilum*, a longitudinal section in the rock, showing the characteristic structure; *b*, *Gonioceras anceps*, a longitudinal section. (I. F.)

the inside but without pores in the walls of the tubes. Of other characteristic fossils, the cephalopods *Actinoceras* (Fig. 1096 *a*) and *Gonioceras* (Fig. 1096 *b*) and the ostracod *Leperditia fabulites* (Fig.

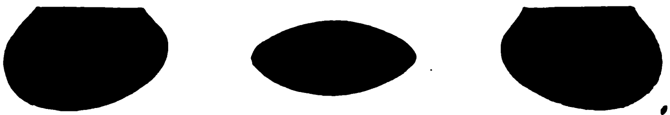


FIG. 1097. — *Leperditia fabulites:* opposite valves and view from below (× 2). A characteristic ostracod of the Black River formation.

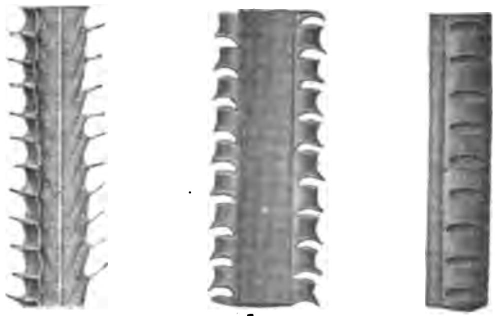
1097) may be noted. Then follow the *Trenton limestones* (Fig. 1098) typically exposed at Trenton Falls, near Utica, and abounding in fossils (Fig. 1099). They are in turn succeeded by the *Utica shale* with *Triarthrus* and characteristic graptolites (*Diplograptus* (*Glossograptus*) *quadrimucronatus*, Fig. 1100 *a*, and *Climacograptus typicalis*, Fig. 1100 *b–c*). Over this lies a more sandy

FIG. 1098. — Trenton limestone in creek bank near Three Mile Bay, Clayton quadrangle, New York. (E. O. Ulrich, photo. Courtesy N. Y. State Museum, John M. Clarke, Director.

shale called the *Frankfort*. This is in turn followed by series of thin-bedded sandstones and shales well exposed on the Salmon River at Pulaski, N. Y., from which place they take their name of *Pulaski shales* (Fig. 1101). They are characterized by pelecypods (*Byssonychia radiata*, Fig. 1102 *a*, *Modiolopsis modiolaris*, Fig. 1102 *b*, etc.) and gastropods (*Cyrtolites ornatus*, Fig. 1103, etc.). Together with the Frankfort shales they constitute the *Lorraine* formation. They are capped by a heavy sandstone, the *Oswego*, which forms a

FIG. 1099. — Trenton limestone, in the gorge of East Canada Creek, Trenton Falls, New York, the type locality for this formation. Sherman Falls (lowest of the Trenton Falls), in distance. (Courtesy N. Y. State Museum, John M. Clarke, Director.) For the characteristic fossils of this limestone see Figs. 1066–1068.

fall in the Salmon River, and upon this sandstone rests a variable thickness of red unfossiliferous shales, the *Queenston* series, which forms the top of the Ordovician.



a *b* *c*

FIG. 1100, *a–c*. — Characteristic graptolites of the Utica shale. *a*, *Diplograptus* (*Glossograptus*) *quadrimucronatus*, showing enlargement of part of a stipe compressed in a slightly oblique direction, still showing the cellules on the two sides. — *b*, *c*, *Climacograptus typicalis*: *b*, A lateral view of the concave side, with the surface entire, showing the form of the cell-apertures; *c*, A profile of the same, showing the entire form of the cell-apertures. (After Hall.)

Analysis of the Section. — The first striking difference we note between this and the Champlain section is the absence of the lower Beekmantown beds. But if we go some distance south along the Adirondack border where the Lowville beds have been more eroded, we see the Beekmantown beds (*Little Falls dolomite*) appearing beneath the higher strata. The lower beds are again

FIG. 1101. — View of a typical outcrop of the Pulaski shales (upper Lorraine) on the Salmon River near Pulaski, New York. For characteristic fossils see Figs. 1102, 1103. (Photo by C. H. Shamel.)

uncovered in the northwestern part of the Adirondack region (Fig. 1104). Thus it is evident that in the line of our section the Beekmantown beds are overlapped by the Chazy (Lowville), while the basal sandstone, with which the series begins, is essentially the St. Peter. The Black River limestone is here rich in fossils, many remarkable cephalopods occurring, besides the coral *Columnaria*. The Trenton limestone and Utica shale have their usual character, but a new division, the Frankfort shale, somewhat more sandy, appears above them. From this formation upward, the beds become more sandy until the nearly pure quartz sandstone of the Oswego is reached, completing the change from limestone to black muds, sandy shales, and sandstones.

FIG. 1102 *a, b.* — Characteristic Lorraine pelecypods. *a, Byssonychia radiata; b, Modiolopsis modiolaris.*

Then follow red shales and sands, indicative of comparative aridity. Evidently there is indicated here a shoaling of the water after the formation of the Trenton limestone, until the region became dry land and was finally subjected to arid conditions. All of the higher beds formerly extended at least to the Adirondacks if not over them, and from the fact that they are thicker and coarser in the Appalachian Mountains of Pennsylvania and Maryland, we are led to conclude that these sediments were derived from Appalachia on the southeast and spread progressively over the Appalachian trough.

FIG. 1103. — A characteristic Lorraine gastropod, *Cyrtolites ornatus* (*a*), with enlargement of surface (*b*).

Columnar Sections across New York and Pennsylvania (Fig. 1105). — If we consider a series of columnar sections which show the proportional thickness of the various Ordovician formations, from Albany to Buffalo, or across Pennsylvania from southeast to northwest, we note a very striking change in thickness and character of the formations from east to west. In the east, the Trenton limestone is very thin, sometimes not over 20 feet (Fig. 1106), and in some sections there is no limestone at all, but the *Normanskill shales*, which represent the upper Chazy and perhaps the Black River as well, are followed directly by dark shales more or less like the Utica shale, and these in turn are succeeded by more sandy beds and finally by sandstones, the whole being several thousand feet thick.

FIG. 1104. — Bared surface of Theresa dolomite (Lower Beekmantown) showing solution along joint fissures. The stream here flows for some distance underground, breaking forth as a large spring. One mile west of Lafargeville, New York, in the Thousand Island region. (H. P. Cushing, photo: courtesy N. Y. State Museum, John M. Clarke, Director.)

As we proceed westward, the Trenton limestone increases in thickness at a fairly regular rate by the progressive appearance of

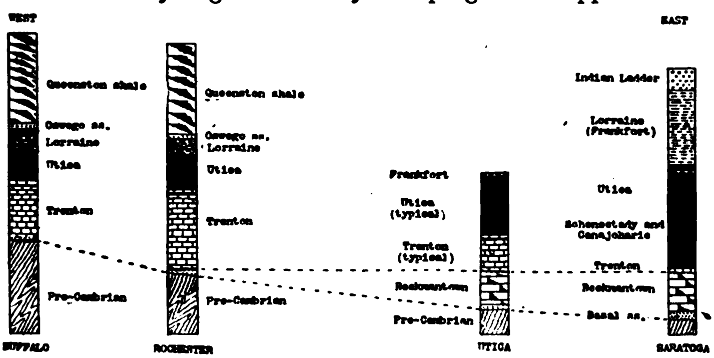


FIG. 1105. — Series of columnar sections across New York showing the change in the character of the Ordovician sediments from east to west. 1, Saratoga–Altamont region; 2, Utica region; 3, Rochester region; 4, Niagara–Buffalo region. (Original.)

higher members. Everywhere the limestone is followed by black shale and this by sandy shales and sandstones, but as the limestones increase the shales and sandstones decrease in thickness. Finally, at Buffalo and in Canada, farther northwest, the Trenton limestones reach nearly a thousand feet in thickness, while the shales and sandy beds are less than half the thickness which they have in the east.

Explanation of these Sections. — There are two ways in which these progressive changes may be explained. In the first place, we may consider that Trenton limestones of more or less uniform thickness (the maximum) were deposited over the region, after

FIG. 1106. — Black marble (Lowville or Amsterdam) and overlying thin-bedded lower Trenton (Glens Falls) limestone, in quarry at Glens Falls, New York. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

which the more easterly districts became subject to erosion, a large part of the limestones being again removed. Then followed the deposition of the clastic beds. At first black muds from Appalachia were spread over the surface, followed by sands, muds, and finally by pure sands, the thickness decreasing away from the source. If this were the case, the contact between the limestone and black shale next above it should be an erosion contact, and the first mud beds above it should be essentially of the same age everywhere or only a little older in the east. This is illustrated in the following diagram (Fig. 1107).

The second mode of explanation is based on lateral change in sediments. According to this view, the lowest member of the Trenton formation was not a limestone in the east near the shore, but a mud-rock, the two merging laterally. As time continued, more limestones were deposited in the pure open western waters, while the muds from Appalachia spread farther west, and covered the first limestone bed for some distance westward, merging finally into the second limestone bed. The mud zone continued to spread in the same direction, occupying more and more territory formerly characterized by limestone deposition, but each layer merging westward into corresponding limestones. As the mud zone spread, the succeeding sandy zone also spread in the same direction, so that the black muds were followed by sandy

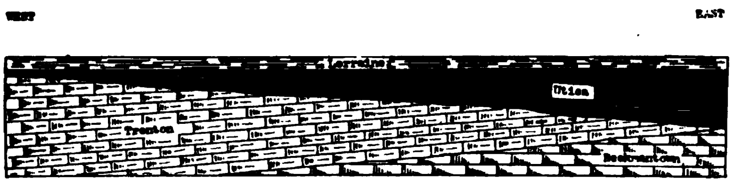


FIG. 1107. — Diagram showing the hypothetical relation of the Trenton limestone and Utica shale on the assumption that the two are separated by a hiatus and that the basal members of the black shale are essentially of the same age throughout. (Original.)

beds. The sandy beds of the west begin at a higher level than the sandy beds in the east, just as the base of the black mud begins at a progressively higher level as we proceed westward. Thus we have a replacing relationship of the limestones and the shales and sands.

Such an explanation implies that the limestone and black mud are everywhere conformable, and indeed pass one into the other. It further implies that the age of the first black mud bed is not the same in all localities, but that it becomes younger as we go westward.

These are the conditions actually found, for not only does the Trenton limestone everywhere pass conformably into the overlying black shales with frequent alternations or interfingerings of shale and limestone at the contact, but the age of the first black bed also varies from place to place. In the east, where the limestone is thin or absent, the black mud-rock, known as *Canajoharie shale* (Fig. 1108) is older than the typical Utica shale which overlies several hundred feet of limestones, which themselves are the equivalent of the eastern black shale (Canajoharie). In the Hudson valley the entire Ordovician series is represented by shales and sandstones, these constituting the *Hudson River* series. In

Fig. 1108. — Canajoharie shale, of Trenton age. This is a deep black, bituminous shale (of the Utica shale type), which replaces the Trenton limestone, shown farther west in Trenton Falls gorge (Fig. 1099). It rests upon the lower thin-bedded Trenton limestone (Glens Falls limestone), shown in the photograph lower down in this gorge (Fig. 1084, p. 272). This same limestone is also shown in the upper part of the section, Fig. 1106. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

Pennsylvania, the series is called the *Martinsburg shale* (Fig. 1109). In the west, the age of the black mud bed is younger than Utica, representing Frankfort or even Lorraine horizons. Thus it is evident that muds and sands were slowly encroaching over the Appalachian trough, pushing the zone of limestone formation farther and farther westward. The relationship is shown in the following diagram (Fig. 1110). As in the case of the Utica, the eastern black shales are characterized by graptolites (Fig. 1111).

FIG. 1109. — Lower Martinsburg shale dipping gently and characterized by cleavage at right angles. Near Pineburg, Maryland. (After Bassler.)

Economic Significance of this Relationship. — As has been shown in an earlier chapter (p. 352, Pt. I), the black muds of seashore origin are important sources of oil. With the relationship here shown

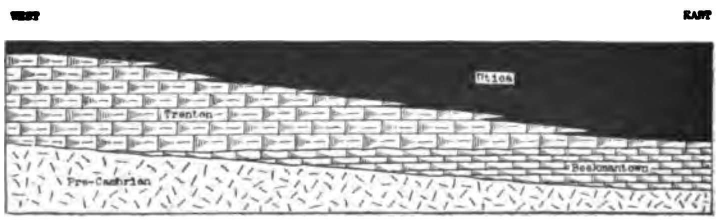


FIG. 1110. — Diagrammatic east-west section showing the replacing relationships of the "Utica" shale and Trenton limestone (replacing overlap). Note that the age of the basal black shale members differs in the different regions and that there is conformity throughout.

it is evident that the distillation products from the organic matter in the black shales may pass slowly westward along the stratification planes into the limestone, where, under favorable conditions of porosity such as those due to dolomitization, and structure (anticlines, domes, etc.), a considerable accumulation of oil and gas may take place. As the limestone is everywhere covered by such shale in addition to passing laterally (eastward) into similar shales, the accumulating hydrocarbons are prevented from escaping upward. In consequence, we find that the Trenton limestone of the interior is in many places an important oil-bearing horizon.


FIG. 1111.—*Lasiograptus eucharis*, compound form (× 4). Trenton (Canajoharie–Collingwood). Upper Ordovician shales.

The Upper Ordovician of the Central and Western Regions. — The Upper Ordovician strata of the central and western United States differ markedly from those of the east. Instead of sandstones and sandy shales, they are mostly limestones with some shales and they are richly fossiliferous. In the exposures around Cincinnati the following divisions are recognized, the eastern equivalents being given opposite.

Cincinnati Group	4. Richmond group — Queenston shale
	3. Maysville group — Oswego sandstone and Pulaski shales
	2. Eden group — Frankfort shales
	1. Galena group — Utica–Trenton series.

The limestone is in places followed by a thin bed of black shale which is regarded as the westernmost extension of the Utica. From what we have seen of the replacement of the Utica by limestones westward, it is probably true that the Galena includes the Utica as well as some of the typical upper Trenton of the east. The three upper divisions are generally classed together as the *Cincinnati* group and they are rich in fossils, among which bryozoans and brachiopods play an important part, often forming entire beds of limestone. There is probably a hiatus or break between the Maysville and Richmond, though it has not been recognized in the Cincinnati region. Over the greater part of the interior, however, from the upper Mississippi valley west to the Rocky Mountains, and north and south of this, the break at the base of the Richmond is very marked. Generally, the Richmond (*Maquoketa*) rests directly upon the eroded surface of the Galena limestone; in some sections a part of the other formations may intervene. This shows

FIG. 1112. — *Cyclora minuta*, the protoconch of a gastropod. This occurs in enormous numbers in some strata and is the source of the Tennessee phosphates. (× 6.) (I. F.)

FIG. 1113. — Section in central Tennessee, showing the Upper Ordovician limestones with weathered surfaces, the product of weathering (chiefly the residual shells of *Cyclora minuta*, Fig. 1112, left on solution of the rock), accumulating in depressions and forming the phosphate rock (ph). The weathered phosphate-bearing surface is covered by late Palæozoic black shale, in the lower part of which some phosphate beds also occur. (After Hayes and Ulrich, Columbia folio, U. S. G. S.)

a widespread withdrawal of the sea, probably at the time of the deposition of the continental Oswego sandstone. Erosion followed, and then the sea returned and the Richmond beds were deposited.

FIG. 1114. — Robson Peak, British Columbia, showing massive Ordovician limestones, 3000 feet thick, overlying Cambrian beds. (After Walcott.)

On account of this interval, and because in the western sections the Richmond beds include some advance types of the Silurian fauna, this horizon has been placed by some in the base of the Silurian. Where normally developed, however, the character of its fauna is undoubted Upper Ordovician.

In central Tennessee, the Middle Ordovician beds have become deeply eroded with the formation of solution pockets, the erosion surface being subsequently covered by late Palæozoic black shale. The Ordovician beds contain vast numbers of early pelagic shell-stages (protoconchs) of gastropods (*Cyclora minuta*, Fig. 1112), and because of the phosphatic character of these shells, they form valuable deposits of phosphate of lime when concentrated in the pockets. The relations are shown in Figure 1113. In the Cordilleran trough of western North America, the Ordovician is very largely represented by limestones of great thickness, from which have been carved many of the lofty mountain peaks of Utah, Nevada and the Canadian region (Fig. 1114).

Closing Stages of the American Ordovician

In the Hudson valley of New York and in parts of Pennsylvania, the Ordovician beds are strongly folded, and the folds are truncated across by an erosion plane. Upon this, and therefore unconformable with the lower series, are found Upper Silurian, and in some places Middle or late Lower Silurian, beds, and although these have also been disturbed by later movements, the unconformity between the two is very marked (Fig. 1115). From this we conclude that the Ordovician beds were folded, at least in parts of the Appalachian trough, toward or after the end of that period, producing mountain ranges where formerly the region was one of sub-

FIG. 1115. — Unconformity between Hudson River sandstones (nearly horizontal) and Shawangunk conglomerate, steeply inclined and slightly overturned to west. Near Port Clinton, Pennsylvania.

sidence and deposition. The present Taconic Mountains on the border line of New York and Massachusetts are formed of these folded Ordovician rocks, and for that reason the disturbance in question is generally called the *Taconic Revolution.*

This disturbance extended northward through Vermont and the present St. Lawrence Valley, and affected the Ordovician and older strata of New Brunswick, Nova Scotia, and other regions. At the same time there appeared deep-seated intrusions of igneous material in many parts of New England and eastern Canada, and these, together with the heat generated by the folding, metamorphosed many of the older sediments. Thus the Cambrian and early Ordovician limestones of Vermont were altered to marbles, and the mud-rocks of Vermont and eastern New York were changed to roofing slates.

During this period of folding, several of the domes of the interior region also had their first important upward movement, among these being the Cincinnati Dome, while the Nashville Dome to the south appears to have had an initial upward arching at an earlier period.

Ordovician of Europe and Asia

The Ordovician deposits of Europe are mainly confined to the Baltic and the Mediterranean regions, for at that time both were embayments from the Atlantic as they are today. The Baltic geosyncline, however, covered England and Wales and part of southern Scotland as well, and its northeastward extension included a considerable area in Norway and Sweden, on the north, and northern Russia on the east. The Mediterranean embayment extended to Bohemia and some distance beyond. In Asia, the main Ordovician basin was that of Irkutsk in Siberia which, it will be recalled, was a southward extension from the Arctic.

Fig. 1116. — *Megalaspis limbata.* Pygidium. A characteristic Lower Ordovician trilobite of Europe.

As we have seen, toward the end of the Cambrian occurred the great transgression which resulted in the formation of the transition deposits (Tremadoc or *Ceratopyge* beds), over the eroded surfaces of the older rocks. By this time the Baltic and Siberian seas had become confluent. Then followed deposition of shales and sandstones (*Arenig*) in the British region, these enclosing, besides many other fossils (trilobites, etc.), the characteristic graptolites: *Tetragraptus* (Fig. 1071), *Phyllograptus* (Fig. 1070), etc., also found in the Deepkill and other shales of eastern America.

Fig. 1117. — Sea-cave in cliffs of Durness limestone (Cambro-Ordovician) Smoo Cave, Durness, Sutherland, Scotland. (Geol. Survey of Great Britain, photo; from Lake and Rastall.)

In the Siberian region, on the other hand, limestones were formed, and these include characteristic trilobites with large pygidia belonging to the genus *Megalaspis* (Fig. 1116). These limestones extended eastward into the Baltic provinces of Russia and into southern Sweden, etc., where they came in contact with the graptolite shales and more or less interfingered with them. In northwest Scotland, the Lower Ordovician is wholly represented by limestones (*Durness limestone*, Fig. 1117), which rest disconformably upon Lower Cambrian limestones of similar character. These relations are shown in the following ideal section (Fig. 1118).

The great St. Peter emergence is also marked in this region, for everywhere the Ordovician rocks are terminated by an erosion plane, above which follow the Middle Ordovician beds. In Great

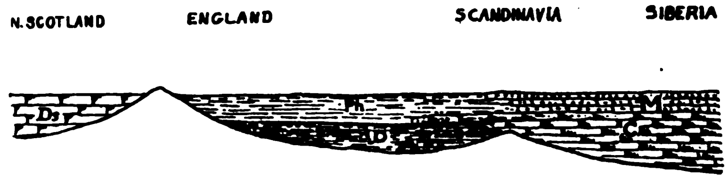


FIG. 1118. — Ideal section illustrating the relationships of the several types of Lower Ordovician deposits in North Europe. North Scotland: *Ds*, Durness limestone (see Fig. 1032). England: *D*, *Dictyonema* shales; *Ph*, *Phyllograptus* shales. Siberia: *C*, *Ceratopyge* limestone; *M*, *Megalaspis* limestone. (After Grabau.)

Britain these Middle Ordovician deposits are known as the *Llandeilo* series, and they contain some heavy continental conglomerates, though largely made up of shales and sandstones. Graptolites (*Dicellograptus*, Fig. 1075 *a–c*, *Climacograptus*, Fig. 1074 *a*, etc.) are very characteristic, the upper Llandeilo beds having practically the same graptolites that are found in the Normanskill rocks of America. These beds often show the distribution and character of near shore or delta deposits. As in America, the transgressive Middle Ordovician beds show overlap in their several members, but there is no intervening sandstone of the St. Peter type. In Russia, too, and in Scandinavia, the overlap of the transgressing Middle Ordovician series is marked, the beds being largely composed of limestones and characterized by *Asaphus expansus* (Fig. 1119), and other trilobites. The relationship of the Lower to the Middle Ordovician beds in this region is shown in diagrammatic manner in the following ideal section (Fig. 1120). The Lower and Middle Ordovician limestones of the Baltic region are generally known as *Orthoceras* limestone from the abundance of orthoceran cephalopods (Fig. 1121). In northern France, on the south side

FIG. 1119. — *Asaphus expansus*, a characteristic Middle Ordovician trilobite of Europe.

of the Baltic embayment, a similar disconformable relation exists between the Middle and Lower Ordovician.

Turning to the Mediterranean embayment, we find the Lower Ordovician beds represented by the transition (Tremadoc) shales

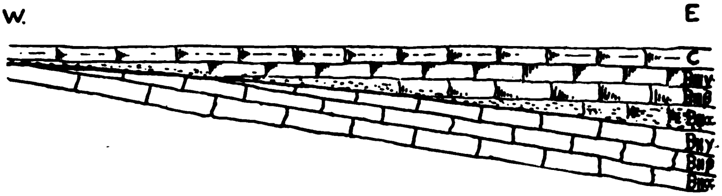


FIG. 1120. — Diagrammatic west-east section in the Baltic provinces of Russia, showing the relation of the Lower Ordovician, retreatal series and the Middle Ordovician transgressing series. Note how the lost interval between the adjoining beds of the two series increases westward. Characteristic fossils of these beds: *BIIa*, *Megalaspis limbata* (Fig. 1116, p. 294); *BIIβ* and *γ*, by other species of *Megalaspis*; *BIIIa*, *Orthis calligramma* (Fig. 1132, p. 303), *Asaphus expansus* (Fig. 1119, p. 296, also in *BIIIβ*); other species of *Asaphus* and cephalopods occur in *BIIIγ*. *C*, *Echinosphaerites aurantium* (Fig. 1140 *d*, p. 307).

and by a greater or less thickness of the Arenig in southern Spain and southern France. In both regions they are followed disconformably by the Middle Ordovician, which in Spain may overlap the older Ordovician rocks (as it does on the western flanks of the

FIG. 1121. — Orthoceras limestone (Ordovician) of Kinnekulle, Sweden.

Adirondacks and in parts of Canada) and rest directly on pre-Ordovician rocks. The basal sandstone is characterized by tracks (*Cruziana*, Fig. 1122) and other markings. In Bohemia, finally, transition beds rest upon Middle Cambrian and are succeeded by shales of the Arenig type. Then follows an erosion plane, and above it are various members of the Middle Ordovician which is the transgressive series.

FIG. 1122. — *Cruziana* (× $\frac{1}{5}$) counterpart of trails in the Ordovician sandstones of Penha-Garcia, Basse-Beira, Portugal. (After Delgrado.)

We thus see how widespread is the evidence for the Lower Ordovician (St. Peter) emergence and the subsequent Middle Ordovician submergence which must, therefore, be regarded as one of the major diastrophic movements of the Ordovician.

The Upper Ordovician of England and Wales is composed of limestones and shales (*Bala* and *Caradoc*), corresponding to the Trenton of America and carrying similar fossils. Deposits of this type are also found in Scandinavia (Fig. 1123) and in Baltic Russia and again in the Mediterranean basin, especially in Bohemia. As in North America, *Trinucleus* (Fig. 1124) is a characteristic fossil of the Upper Ordovician beds.

Toward the end of the Ordovician northwest Europe witnessed the same retreat and readvance shown in America by the break

FIG. 1123. — Diabase dike in the *Trinucleus*-limestone on Frognö, Ringerike, Norway. (Photo by Prof. J. Kiær.)

between the Galena and the Richmond beds. But a unique feature of this later retreat appears in Siberia, where extensive red beds like the Queenston were deposited. This indicates the development, in the Irkutsk basin, of arid climatic conditions which are further emphasized by the occurrence of extensive salt deposits with the red beds.

FIG. 1124. — *Trinucleus goldfussi*, a characteristic European Upper Ordovician trilobite. (After Kayser.)

Gypsum also is frequently found in these beds, with or without the salt. If this gypsum is not an alteration product (from limestone) and if it normally underlies the salt (confirmation of which is lacking) it would appear that these salt deposits are the product of evaporating sea-water, either in cut-off basins or in salt pans and lagoons along the retreating seashore of Ordovician time. In that case it might be profitable to explore the formation for potash salts which, as we have seen in a previous chapter, are frequently associated with marine salt deposits.

Igneous rocks are also associated with Ordovician beds of Siberia, but their period of eruption or intrusion is not fully determined. In Great Britain, on the other hand, igneous activity was marked during the Ordovician, both as outpouring of lava-flows and as intrusions. The rocks are, however, little metamorphosed.

FIG. 1125. — ***Brachiospongia digitata***, a characteristic Ordovician sponge. (I. F.)

FIG. 1126.—Base of ***Receptaculites oweni***, Galena limestone, Ordovician. (I. F.)

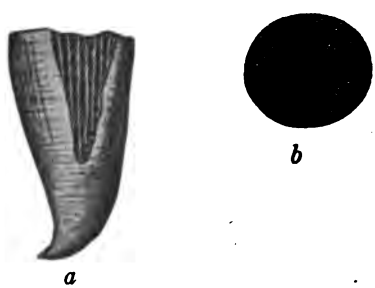


FIG. 1127 *a*, *b*.—***Streptelasma profundum*** (Conrad), specimen broken to show interior of cup; and view of cup from above. A characteristic cup coral of the Black River limestone (Wisconsin).

FIG. 1127 *c–f*.—*c*, ***Streptelasma corniculum***; *d*, section of same; *e*, ***S. rusticum***; *f*, cross-section of same. (I. F.)

FIG. 1128.—***Tetradium cellulosum*** (Hall). Longitudinal and transverse sections. A characteristic coral of the Black River limestone, New York.

Life of the Ordovician

General Character of the Ordovician Fauna. — The distinctive character of the Ordovician fauna as a whole lies in the abundance of graptolites, of Bryozoa and of brachiopods. **Sponges** are, on the whole, rare, but two very striking types occur, one (*Brachiospongia*, Fig. 1125) with long hollow finger-like projections around a central disk with large central opening (osculum), and the other shaped more or less like a jardinière but with contracted opening and a very striking wall structure of rods and cross-bars (*Receptaculites*, Fig. 1126). Generally only the base of this is preserved, the under side of which resembles in arrangement of parts the markings on a machine-turned watch case. The only **graptolites** not represented in the Ordovician are the monograptid forms with the cups or thecæ arranged on one side of the supporting rod or virgula. They are wholly characteristic of the Silurian, from which the other graptolites are absent. **Corals** are still rare, but simple cup corals have appeared (*Streptelasma*, Figs. 1127 a–f), though except for a few species they are not abundant. The compound corals are the large-tubed *Columnaria* (Fig. 1095) (several species) and peculiar forms with almost hair-like prismatic tubes (*Tetradium*, Figs. 1128–1130). The **Bryozoa** are abundantly represented, especially by the solid forms which resemble small corals (monticuliporoids, Fig. 1131). They are composed of numerous fine prismatic tubes generally of two sizes with transverse partitions. The **brachiopods** are numerous and characteristic. The Orthis group, with straight hinge line, which generally forms the greatest width of the shell, is abundant. True

FIG. 1129. — *Tetradium syringoporoides* Ulrich. Weathered-out specimens on a rock surface, natural size, and several cross-sections enlarged 6 times. Characteristic coral of the Stones River (upper Chazy), Maryland. (From Bassler.)

FIG. 1130. — *Tetradium columnare* (Hall). Trenton, New York state. (From Bassler.)

long-hinged *Orthis* abounds in the lower divisions, one valve highly convex, the other nearly flat (Figs. 1063, 1078). A short-hinged Orthis (*Dalmanella*) is also abundant. (See Figs. 1066 *a–c*, p. 264.) Higher up the valves are nearly equal in convexity (Figs. 1132–1133 *d–f*) and in still higher beds the valve with the largest hinge area is the least convex (Fig. 1133 *m–o*). The group of Platy-

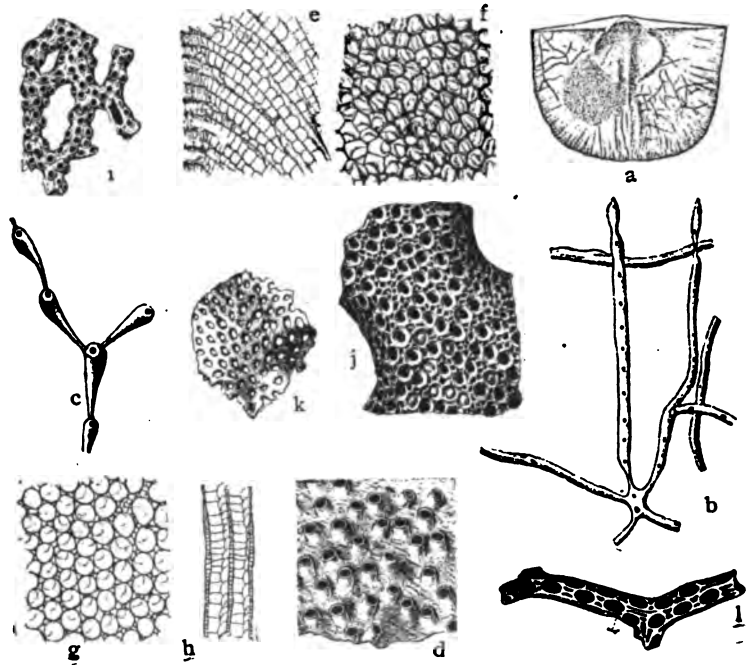


FIG. 1131. — Characteristic Ordovician bryozoans. *a, Vinella repens* on a brachiopod shell (Black River beds); *b*, same (× 18); *c, Stomatopora delicatula* (× 12½) (Stones River to Richmond); *d, Berenicea minnesotensis* (× 9) (Stones River and Black River); *e, Monticulipora arborea*, vertical section (× 9) (Trenton); *f*, same, tangential section (× 9); *g, Prasopora simulatrix*, tangential section (× 9) (Black River and Trenton); *h*, same, vertical section (× 9); *i, Phylloporina reticulata* (× 9) (Black River and Trenton); *j, Stictoporella cribosa* (× ½) (Stones River and Black River); *k*, same (× 9); *l, Nematopora ovalis* (× ½ and × 9) (Trenton). (I. F.)

strophias (Fig. 1133 *g, h*) is also practically confined to the Ordovician. Then there are the thin, flat-valved forms, one valve generally convex, the other concave. Here belong *Plectambonites* (Fig. 1066 *f–h*), *Rafinesquina* (Fig. 1133 *p, q*) and the reversed form, *Strophomena* (Fig. 1133 *l–l'*) all characteristic of the Ordovician, though some are represented in higher rocks. The plicated, biconvex rhynchonelloid shells with blunt beak, no hinge area and deep median indentation on one valve and corresponding elevation on the other, are well represented especially in the Upper Ordovician (*Rhynchotrema*, Figs. 1133 *i–k*) though some more pointed-beaked forms (*Camarotœchia*, Fig. 1065) occur in lower horizons. Other types occur but are less characteristic.

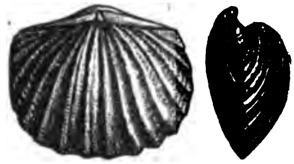


FIG. 1132. — *Orthis* (*Plectorthis*) *calligramma*, a Middle Ordovician brachiopod of Europe, ventral and side views. (After Kayser.)

Certain forms of **pelecypods** are characteristic, especially the peculiar *Ambonychia* and *Byssonychia* with a large wing on one side of the beak (Fig. 1102 *a*). Mussel-like forms (*Modiolopsis*, Fig. 1102 *b*) also occur, but similar forms are found in higher strata. Both high and low spired **gastropods** abound,

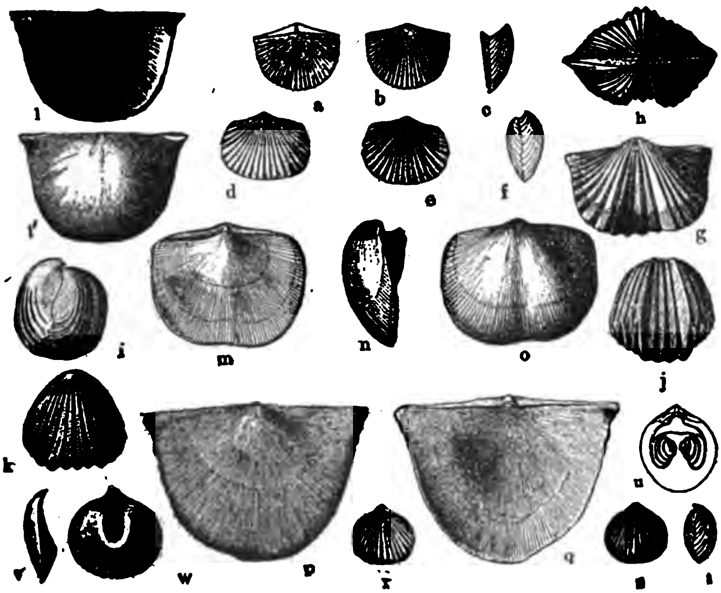


FIG. 1133. — Characteristic Ordovician brachiopods. *a–c*, *Orthis tricenaria* (Stones River and Black River); *d–f*, *Plectorthis plicatella*, Cincinnati gr.; *g–h*, *Platystrophia acutilirata*, Cincinnati gr.; *i–k*, *Rhynchotrema capax*, Cincinnati gr. (Lorraine); *l–l'*, *Strophomena planumbona*, Cincinnati gr.; *m–o*, *Dinorthis subquadrata*, Cincinnati gr.; *p*, *q*, *Rafinesquina alternata*, Trenton–Cincinnati gr.; *r*, *Zygospira modesta*, Cincinnati gr.; *u*, *Z. recurvirostra*, showing spires, Trenton; *v*, *w*, *Trematis millepunctata*, Cincinnati gr. (All × ⅔ except *r–w*, which are enlarged.)

generally with a notch in the margin at the end of a revolving band (Fig. 1135 *d–i*). Flat spired forms of various kinds occur (*Ophileta*, *Maclurea*, Figs. 1059, 1064). There are also many *Bellerophon* types which coil in a single plane

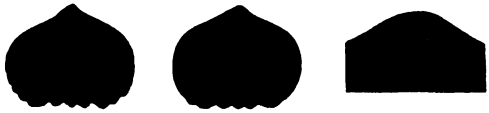


FIG. 1134. — *Orthorhynchula linneyi*. A characteristic brachiopod of the Upper Ordovician. (Cincinnatian.)

like a *Nautilus* shell, but without septa. They generally have a notch in the outer median edge (*Sinuites*, Figs. 1135 *j–l*, *Cyrtolites*, Fig. 1103). The **cephalopods** occur as straight, often very large, forms (orthoceran, Fig. 1136 *a*, *b*),

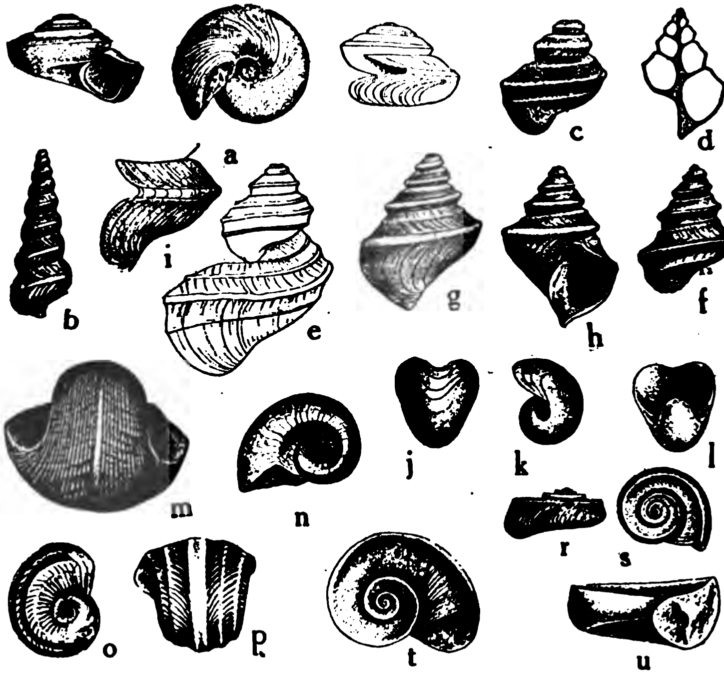


FIG. 1135. — Characteristic Ordovician gastropods. *a*, *Eotomaria supracingulata*, 3 views, Stones River and Black River (× $\frac{1}{2}$); *b*, *Hormotoma trentonensis*, Trenton; *c*, *Lophospira bicincta*; *d*, section of same, Stones River, Trenton, and Cincinnati group; *e*, *Lophospira helictera*, Black River (× $\frac{3}{8}$); *f*, *Lophospira pulchella*, Black River; *g–h*, *L. ampla*, Cincinnati gr.; *i*, *L. tropidophora* (last whorl), Cincinnati gr.; *j–l*, *Sinuites cancellatus*, Trenton to Richmond (× $\frac{2}{3}$); *m–n*, *Bucania sulcatina* (*m* × 1$\frac{1}{3}$, *n* × $\frac{4}{5}$), Chazy; *o–p*, *Tetranota sexcarinata*, Stones River; *r–s*, *Helicotoma tennesseensis*, Stones River, Black River; *t–u*, *Eccyliopteris beloitensis*, Stones River.

curved or cyrtoceran forms (Fig. 1136 *c*), and as coiled forms, generally of smooth exterior and with only slightly impressed zone (Figs. 1136 *d*, *e*). There

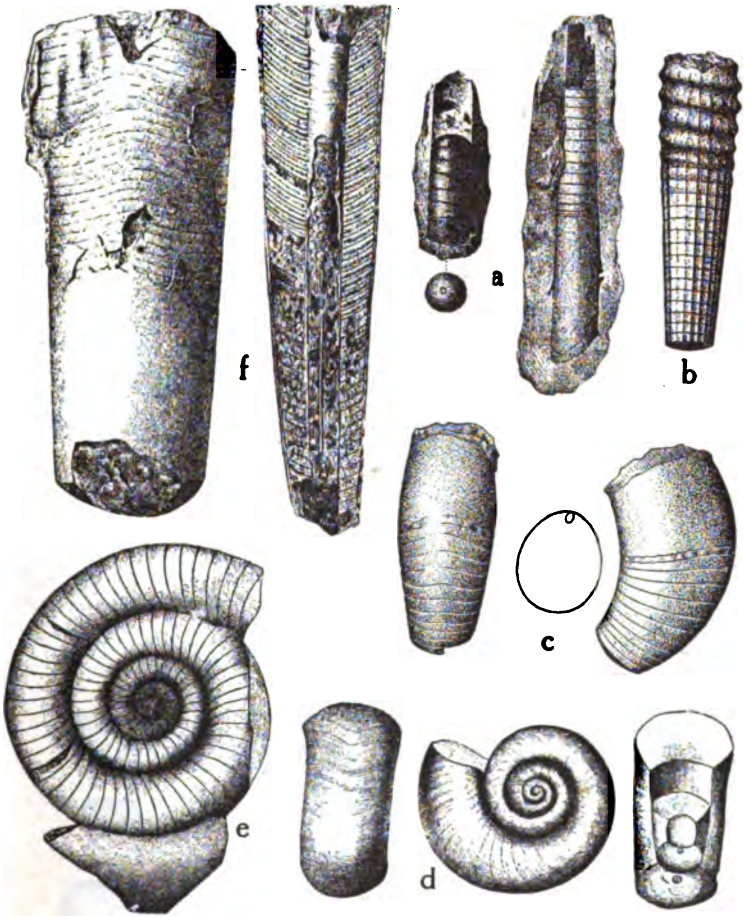


FIG. 1136. — Characteristic cephalopods of the Ordovician of North America. *a*, *Orthoceras junceum*, two specimens, and septal view, Stones River to Trenton; *b*, *Spyroceras bilineatum*, Stones River to Trenton; *c*, *Cyrtoceras* (*Oncoceras*) *pandion*, ventral and lateral views and section, Stones River; *d*, *Trocholites planorbiformis*, a nautiliform type, ventral and lateral views and sections showing the impressed zone, and siphuncle, Lorraine; *e*, *Tarphyceras seeleyi*, a coiled shell with whorls scarcely impressed, a gyroceran type, Beekmantown; *f*, *Cameroceras tenuiseptum*, external view and natural section, Chazy. (All reduced.)

is a peculiar group of straight (more rarely curved) forms, which is confined to this system. In these the septa are pierced by a very large round opening,

FIG. 1137. — *Calymmene senaria.* *a*, A view of cephalic shield and a part of the thorax of an unusually fine specimen; *b*, a lateral view of same; *c*, an anterior view of same, also showing the pygidium, and the posterior part of the thorax.

FIG. 1138. — *Ceraurus dentatus*, a characteristic Trenton trilobite.

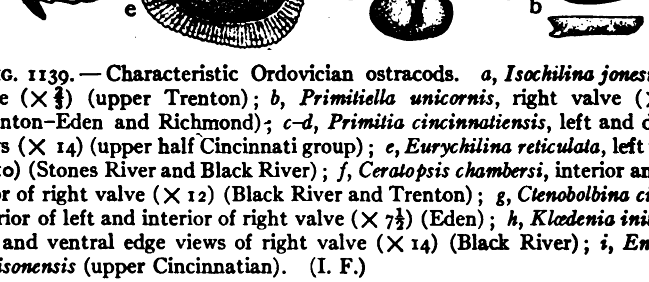


FIG. 1139. — Characteristic Ordovician ostracods. *a*, *Isochilina jonesi*, left valve ($\times \frac{2}{3}$) (upper Trenton); *b*, *Primitiella unicornis*, right valve ($\times$ 14) (Trenton–Eden and Richmond); *c–d*, *Primitia cincinnatiensis*, left and dorsal views ($\times$ 14) (upper half Cincinnati group); *e*, *Eurychilina reticulata*, left valve ($\times$ 10) (Stones River and Black River); *f*, *Ceratopsis chambersi*, interior and exterior of right valve ($\times$ 12) (Black River and Trenton); *g*, *Ctenobolbina ciliata*, exterior of left and interior of right valve ($\times 7\frac{1}{2}$) (Eden); *h*, *Klœdenia initialis*, side and ventral edge views of right valve ($\times$ 14) (Black River); *i*, *Entomis madisonensis* (upper Cincinnatian). (I. F.)

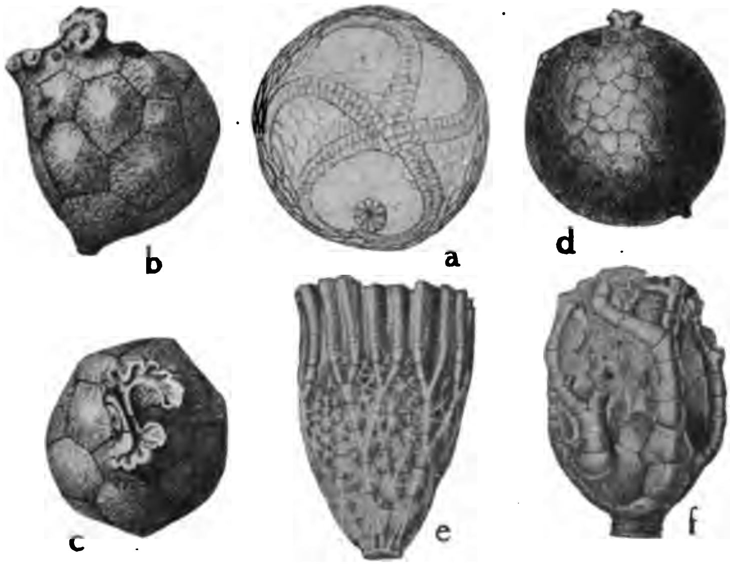


FIG. 1140. — Ordovician cystoids, and crinoids. *a*, *Agelacrinus cincinnatiensis*, Cincinnati group; *b–c*, *Malocystites emmonsi*, side and oral views, Chazy; *d*, *Echinosphærites aurantium*, Middle Ordovician (Stones River or Chambersburg); *e*, *Glyptocrinus decadactylus*, Cincinnati group; *f*, *Anomalocrinus incurvus*, Cincinnati group.

FIG. 1141. — *Pleurocystites squamosus*. Ordovician of Ottawa, Canada. A characteristic cystoid showing stem and two arms, also "pore rhombs."

within which lies a second tube, generally on one side of the outer one. This second tube is mostly filled with solid lime, arranged in close-set cones which, however, generally appear as a solid mass. In worn specimens this sometimes projects beyond the shell. Example *Cameroceras* (Fig. 1136 *f*).

Trilobites are still abundant and characteristic. The most striking are *Isoteles* and *Megalaspis*, with head and pygidium similar and each occupying about one-third of the length (Figs. 1068, 1116); *Calymmene* (Fig. 1137), which often coils into a ball, is well represented but not restricted here. There are also many more or less spiny forms (*Ceraurus*, Fig. 1138), but one of the most characteristic is *Trinucleus* (Figs. 1067, 1124) with the large head marked by three bulging lobes and surrounded by an ornamental flat rim which ends in lateral spines. **Ostracods** were also very abundant (Fig. 1139). **Cystoids** and **crinoids** also occur, and so do **starfish**, but they are generally rare though very characteristic when found, especially the cystoids *Agelacrinus* (Fig. 1140 *a*), *Pleurocystites* (Fig. 1141), *Echinosphærites* (Fig. 1140 *d*), and the ornamental crinoid *Glyptocrinus* (Fig. 1140 *e*). Finally there are many calcareous **algæ**, the most conspicuous among them being *Cryptozoön*, which sometimes makes up entire beds of limestone (Fig. 1058). The river faunas of the Ordovician comprised fish-like animals of the **ostracoderm** group and **eurypterids**, some of which were also washed out to sea and buried with typical marine fossils. No land **plants** are known, but what appear to be remains of **insects** have been obtained from some European localities, though their insect character has been questioned.

FIG. 1142.—Digging for Ordovician graptolites in Scania, Sweden. The rocks are extensively soil covered and fossiliferous rocks can often be exposed only by digging. The late Professor Moberg of Lund, and his assistant. (Photo by author.)

CHAPTER XXXIV

THE SILURIAN OR SILURIC SYSTEM

When in 1835 the English geologist Roderick Murchison determined to undertake the study of the old graywacke rocks of Wales, he decided, after consultation with other geologists and the perusal of local studies made by them, to attack the problem on the borderland between England and southern Wales, for there these ancient rocks were least disturbed, and the exposures promised to furnish more continuous sections than elsewhere in the kingdom. Early in his studies he found that the rocks which lay beneath the base of the Old Red Sandstone series (the Devonian) represented a system hitherto unknown in the sequence of geological formations and were characterized by congeries of organic remains quite unlike any then known, and of more ancient aspect than those found in the systems heretofore differentiated. Casting about for a name to apply to this newly-to-be erected system, he determined to immortalize one of the most warlike and heroic ancient Celtic races, the Silures, who, under their redoubtable King Caradoc, most effectively resisted to the last the invasion of Cæsar's legions. It was, indeed, in the ancient domain of this people that some of the best sections of these younger graywacke rocks were exposed, and the name "Silurian system" was most fittingly applied to the formations, the study of which carried geological knowledge a step lower in the scale of stratigraphic succession. The establishment of this system and its naming in 1835 marked an epoch in the history of geological science, and when in 1838 the ponderous work entitled *The Silurian System* appeared, the reputation of its author was established throughout the scientific world, and thereafter colleagues as well as kings delighted to honor him and to seek his advice. From this time on, Sir Roderick devoted most of his energies to the extension and further development of the knowledge of this system at home and abroad, in which endeavor he was ably seconded by the great French geologist, later a resident of Bohemia, Joachim Barrande, by noted colleagues in Sweden, and by the geologists of North America, of whom James Hall of New York state was the most eminent.

Murchison subdivided his Silurian system into an upper and a lower division, and although the rocks of the lower division cover more territory in the old country of the Silures, they were, as we have seen, essentially of the age of the rocks designated Upper Cambrian by Sedgwick in the north of Wales. As was perhaps inevitable, a long controversy arose over the name to be applied to this division, which all came to realize was the middle member of the threefold group into which the old graywacke rocks naturally fell. This controversy was finally brought to a close, as we have seen, by the adoption of the new name Ordovician for the Lower Silurian rocks of Murchison's system and the restriction of the name Silurian to his Upper Silurian division.

These rocks are best exposed in western England, where they are little disturbed, and where they are finely shown in the great

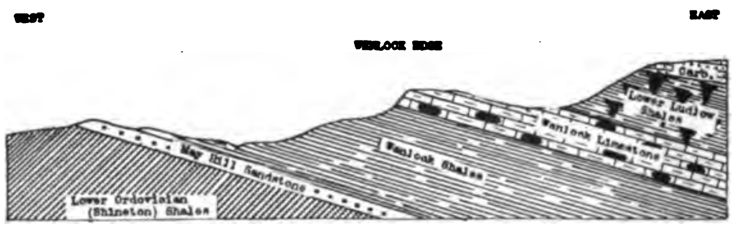


FIG. 1143. — Cross-section of the Silurian strata of Shropshire, western England. The Silurian (Niagaran) strata rest unconformably, and with a basal sandstone, upon Lower Ordovician shales, and are disconformably succeeded by Coal-measure sandstones (Carb.). The principal Silurian limestone (Wenlock) forms the prominent Wenlock edge or cuesta. It contains numerous reef-like masses, the so-called ball-stones. (From the author's field notes.)

cuesta front, known as the Wenlock edge, which faces the oldland of Wales (Fig. 1143). Here they abound in fossils of many kinds, including corals, brachiopods, and trilobites; whereas in Wales the rocks of this age are seldom very fossiliferous, graptolites being often the only organic remains found in them. Other exposures in England also carry numerous fossils of great variety, while in southern Scotland graptolite-bearing shale is almost exclusively developed. This is also the case to a considerable extent in Norway and Sweden, though there, as in the Ordovician system, limestones with other fossils become important members of the series. On the island of Gotland, in the Baltic, the most complete succession of these rocks in Europe is known, represented almost wholly by calcareous beds, and with a wealth of organic remains equaled only by the rocks of this system in North America (Fig. 1144). In the Baltic provinces of Russia and over wide areas under

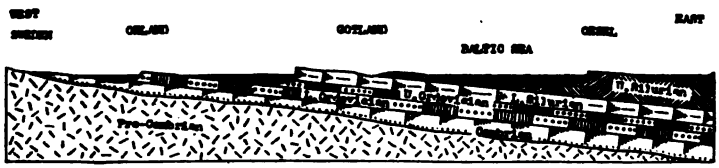


Fig. 1144 *a*. — Section from the coast of Sweden eastward, across the islands of Öland, Gotland, and Oesel to the Baltic coast of Russia (Esthonia), showing the relationships of the Cambrian, Ordovician, and Silurian strata and the submerged lowlands. (Original.)

the flat Russian plains to the border of the Ural Mountains, rocks of this age, rich in fossils, are found, and their lower portion is well represented in the basin of Bohemia, where again they are extremely fossiliferous, some beds of limestone consisting almost entirely of organic remains.

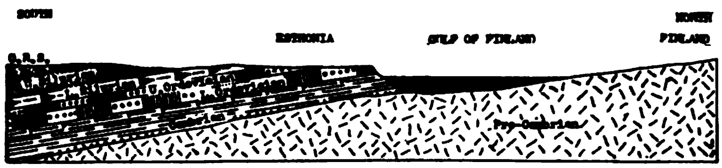


Fig. 1144 *b*. — Section southward from Finland across the Gulf of Finland and part of Esthonia, showing the relationships of the Cambrian, Ordovician and Silurian strata capped by Old Red Sandstone. Also the partly submerged Esthonian cuesta, and inner lowland (Gulf of Finland). (Original.)

But it is to North America that we must turn for the fullest representation of the rocks of this system, and again the state of New York takes first rank among the districts in which the system is most fully developed, and the names of the standard American subdivisions are largely derived from New York localities. Other American regions important to the student of the Silurian rocks are Wisconsin, Michigan, Ohio, and eastern Canada, especially the island of Anticosti in the Gulf of St. Lawrence, and finally the southern Appalachians, the last-named district furnishing the most complete representation of the continental phases of the Silurian formations. Noted localities for the fossils of the lower division are the Falls of the Ohio at Louisville, Kentucky, and

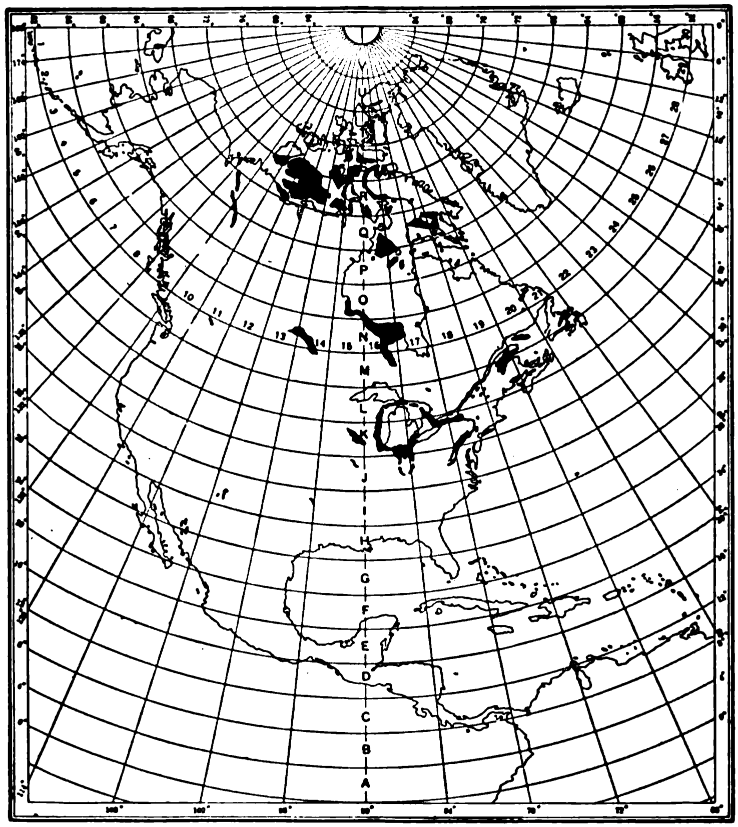


FIG. 1145. — Map showing the outcrops of Silurian rocks in North America. (After Bailey Willis.)

parts of western Tennessee and Indiana. On the south shore of Hudson Bay Silurian rocks cover large areas (Fig. 1145).

Silurian formations occur in other parts of the world as well, including the Arctic region of America and Asia, but few of these have as yet been studied in detail.

General Relationships of the Silurian to the Preceding Formations

The close of the Ordovician seems to have been marked by a widespread withdrawal of the sea from the continents, and the opening of the Silurian by a renewal of transgression of the oceans over the lands. This is indicated by the fact that in all but a few localities the Silurian beds rest disconformably (in some cases unconformably) upon the Ordovician, there being a recognizable, though generally not very profound, erosion break between the two systems. That the Silurian transgression extended beyond the regions covered by that of the Ordovician is shown both in America and Europe by the fact that in some localities the base of the Silurian rests unconformably on the crystalline rocks. Only in the northern end of the Appalachian geosyncline (Anticosti Island) is a perfectly conformable succession of the Silurian upon the Ordovician seen, with a bed carrying organic remains of both between them. A less perfect transition is found in the southern part of the geosyncline (lower Mississippi Valley). Others may, however, be discovered in the future.

The Silurian of North America

General Subdivision

A threefold subdivision of the Silurian is recognizable in North America, of which the lower and upper are represented principally by marine formations, while the middle division is a non-marine series. These subdivisions are as follows:

Upper Silurian or Monroan — largely marine.
Middle Silurian or Salinan — non-marine.
Lower Silurian or Niagaran — chiefly marine.

The lower division is best known from the Niagara River section, from which the series is named. The middle division is best developed in central New York and in southern Michigan, where it carries deposits of rock salt. The upper is best known from southeastern Michigan and the adjoining districts of Ohio and Ontario. Its name is derived from Monroe County, Michigan. In New York state only a part (chiefly the upper) of the Monroan series is present.

New York State Subdivisions

The following Silurian formations occur in the state of New York, though they are not always developed in the same sections:

UPPER SILURIAN OR MONROAN
- *Upper Monroan.*
  - Manlius Limestone.
  - Rondout Waterlime.
  - Cobleskill and Akron Limestones (approximate equivalents).
  - Rosendale and Bertie Waterlimes (approximate equivalents).
  - Wilbur Limestone, and Camillus Shale (in part).
- *Middle Monroan* (usually absent).
  - Binnewater Sandstone (partial representative).
- *Lower Monroan* (mostly absent).
  - High Falls Shale (partial representative).

MIDDLE SILURIAN OR SALINAN
- Camillus Shale and Gypsum (in part).
- Syracuse Salt Series.
- Vernon Red Shale.
- Pittsford Shale and Shawangunk Conglomerate (in part). (These may belong to the Upper Niagaran.)

LOWER SILURIAN OR NIAGARAN
- *Upper Niagaran.*
  - Guelph Dolomite and Shawangunk Conglomerate (in part).
  - Lockport Dolomite and Limestone.
- *Middle Niagaran.*
  - Rochester Shale.
  - Clinton Limestones and Shales.
- *Lower Niagaran* or Medina Group.
  - Thorold Quartzite and Oneida Conglomerate (partial equivalents).
  - Medina Sandstones and Shales.
  - Whirlpool Sandstone.

ORDOVICIAN QUEENSTON SHALES

Characteristic Sections

Several sections may first be given to show the present structural and stratigraphic relations of the Silurian strata in North America.

The Niagara River Section. — The section along the Niagara River from Lewiston to Buffalo is in many respects the most typical as well as the classic section of the North American Silurian (Fig. 1146). At the mouth of the great gorge near Lewiston, the lower banks of the river are formed by the brick-red Queenston shales, which form the top of the Ordovician (Fig. 1147). They are capped abruptly by a white quartzose sandstone 25 feet thick (the *Whirlpool sandstone*) which can be traced to the Whirlpool.

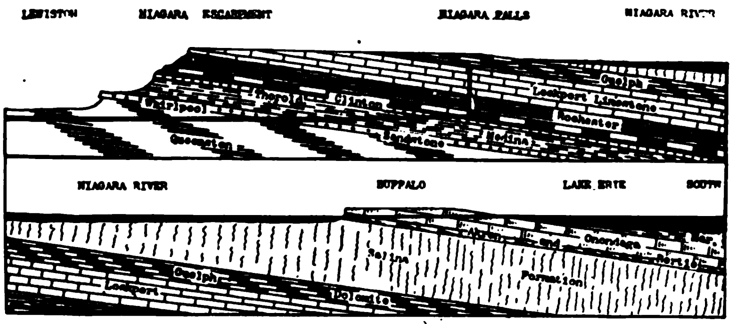


FIG. 1146. — Section from Lewiston, N. Y., across the Niagara escarpment (cuesta) to Buffalo showing the Silurian formation resting with a basal sandstone (Whirlpool) upon the Upper Ordovician red Queenston shales. The rocks are fully exposed in the walls of Niagara gorge, as far as Niagara Falls. The Middle Silurian beds (Salina) are covered; the Upper Silurian or Monroan is represented only by its upper members (Bertie and Akron or Cobleskill) there being a hiatus between the upper Monroan and the Salinan. The Onondaga Limestone (Middle Devonian) rests disconformably upon the upper Monroan (Akron) and is followed by the black Marcellus shale. (Original.)

FIG. 1147. — Whirlpool white sandstone, at the base of the Medina, resting upon red Queenston shales and succeeded by red shales and sandstones of the Medina group. The base of the Whirlpool sandstone marks the base of the Silurian system in this section. Niagara gorge, opposite Foster's Flats. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

Fig. 1148. — Section in Niagara gorge on N. Y. Central R. R., above Lewiston. The upper red Medina shales and sandstones are seen above the track (*d*) capped by the White Thorold quartzite (*c*): Above this lies the Clinton shale (*b*), covered in turn by the Clinton limestones (*a*). (Courtesy N. Y. State Museum, John M. Clarke, Director.)

Fig. 1149. — Beach markings of stranded shells on surface of Medina sandstone. Lockport, N. Y. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

Above this follow green and red shales and red sandstones, the typical *Medina* beds, and this division is terminated by a bed of white quartzite ten feet thick (*Thorold quartzite*, Fig. 1148). These three divisions constitute the Medina group. The coarser sandstones are generally crossbedded and show channel scouring, irregularity of bedding, ripple-marks, rill-marks, wave-marks, and beach cusps, all indicative of seashore deposition (Fig. 1149). Some of the beds, especially in the lower part of the middle division, are fossiliferous, a common fossil being the brachiopod *Lingula cuneata* (Fig. 1150). In some of the shaly layers in the upper part of the series is found the remarkable trail of an unidentified organism (usually referred to an an-

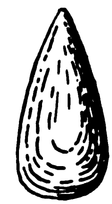


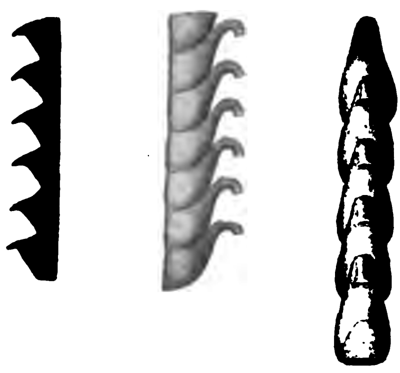
FIG. 1150. — *Lingula cuneata*, a characteristic brachiopod of the Medina sandstone, × 1½.

FIG. 1151. — Section in Niagara gorge, along N. Y. Central R. R., south of the section shown in Fig. 1148. At the base in the foreground the top of the Thorold quartzite (*e*) is shown; above this lie the Clinton shales (*d*) 6 feet thick; then follows the lower Clinton limestone (*c*) 15 feet thick; and the more massive upper Clinton or Irondequoit limestone (*b*) 11 feet thick. This is overlain by the Rochester shale (*a*). The full thickness of this shale (68 feet) is seen in the middle distance of the view, where it is capped by the Lockport dolomite which forms the upper cliff. (Courtesy N. Y. State Museum, John M. Clarke, Director.

nelid), known as *Arthrophycus harlani* (Fig. 759), and always preserved in relief expression on the under side of the sandstone which covers the bed with the actual trail. The Medina group is followed by the beds of the *Clinton* group, a thin shale and two limestone formations about 40 feet thick (Fig. 1151). Then

FIG. 1152. — *Anoplotheca* (*Cœlospira*) *hemisphærica*, a characteristic brachiopod of the Atlantic or Clinton type of Silurian fauna; England and eastern North America. Pedicle valve and side view; enlarged three diameters.

FIG. 1153. — *Pentamerus oblongus*, characteristic of the Atlantic phase of the Niagaran (Clinton type) of western Europe and eastern North America.



a *b* *c*

FIG. 1154. — *Monograptus clintonensis*. *a*, a flattened fragment from near the base of the branch (× 6); *b*, lateral view of part of mature stipe (× 6); *c*, front view of same (× 9). Clinton shales. Rochester region. (After Hall.)

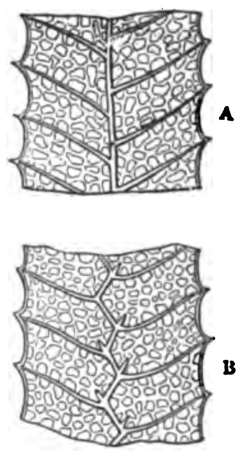


FIG. 1155. — *Retiolites venosus* Hall. *A*, from exterior, showing external axis and cell partitions. *B*, interior, showing zigzag axis and cylindrical process extending to the margin, and short, apparently broken processes (× 9). Clinton shales. (After Hall.)

follows a 70-foot bed of shale (*Rochester shale*) and the cliff is terminated by a 25-foot limestone bed (lower *Lockport dolomite*).

FIG. 1156. — Section in the New York Central railroad cut in the gorge of Niagara River, below the Whirlpool. The rock at the level of the track is the upper Clinton or Irondequoit limestone (sometimes classed as a member of the Rochester) overlain by typical Rochester shale. The top of the Irondequoit shows a lens-like bryozoan reef about 30 feet long composed of fine calcareous mud held together by the fronds of branching Bryozoa. These grew upon the sea-bottom in this locality and were slowly buried by the accumulating mud, new colonies developing as the old ones died and were buried. Numerous other organic remains are found in these reef mounds. Reefs of this type are very common in this formation in western New York. (G. K. Gilbert; photo; from U. S. Geological Survey.)

These beds are all more or less richly fossiliferous. The Clinton contains chiefly brachiopods, among which *Cœlospira hemisphærica* (Fig. 1152) is most common. *Pentamerus oblongus* (Fig. 1153), though abundant in this limestone farther east (at Rochester), is rare at Niagara. In black shale bands, in the Rochester, N. Y., region the graptolites *Monograptus clintonensis* (Fig. 1154) and *Retiolites venosus* (Fig. 1155) are not infrequent.

FIG. 1157. — *Caryocrinus ornatus*, a Lower Silurian (Niagaran) cystoid.

At the top of the Clinton limestones reef-like masses formed by the growth of Bryozoa are not uncommon (Fig. 1156). The Rochester shale abounds the southern Appalachians, the last-named district furnishing the most complete representation of the continental phases of the Silurian formations. Noted localities for the fossils of the lower division are the Falls of the Ohio at Louisville, Kentucky, and

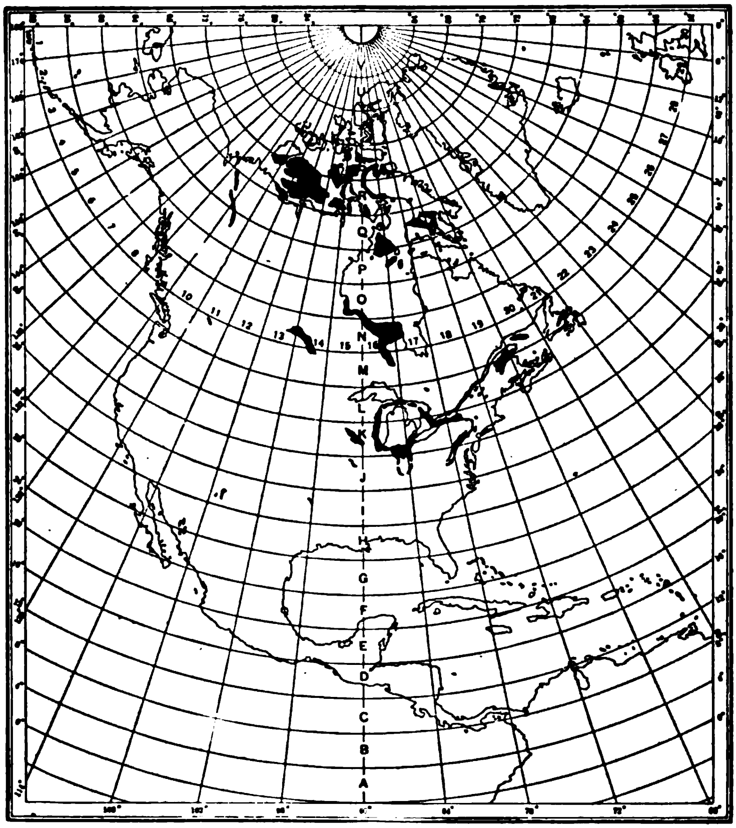


FIG. 1145. — Map showing the outcrops of Silurian rocks in North America. (After Bailey Willis.)

parts of western Tennessee and Indiana. On the south shore of Hudson Bay Silurian rocks cover large areas (Fig. 1145).

Silurian formations occur in other parts of the world as well, including the Arctic region of America and Asia, but few of these have as yet been studied in detail.

General Relationships of the Silurian to the Preceding Formations

The close of the Ordovician seems to have been marked by a widespread withdrawal of the sea from the continents, and the opening of the Silurian by a renewal of transgression of the oceans over the lands. This is indicated by the fact that in all but a few localities the Silurian beds rest disconformably (in some cases unconformably) upon the Ordovician, there being a recognizable, though generally not very profound, erosion break between the two systems. That the Silurian transgression extended beyond the regions covered by that of the Ordovician is shown both in America and Europe by the fact that in some localities the base of the Silurian rests unconformably on the crystalline rocks. Only in the northern end of the Appalachian geosyncline (Anticosti Island) is a perfectly conformable succession of the Silurian upon the Ordovician seen, with a bed carrying organic remains of both between them. A less perfect transition is found in the southern part of the geosyncline (lower Mississippi Valley). Others may, however, be discovered in the future.

The Silurian of North America

General Subdivision

A threefold subdivision of the Silurian is recognizable in North America, of which the lower and upper are represented principally by marine formations, while the middle division is a non-marine series. These subdivisions are as follows:

Upper Silurian or Monroan — largely marine.
Middle Silurian or Salinan — non-marine.
Lower Silurian or Niagaran — chiefly marine.

The lower division is best known from the Niagara River section, from which the series is named. The middle division is best developed in central New York and in southern Michigan, where it carries deposits of rock salt. The upper is best known from southeastern Michigan and the adjoining districts of Ohio and Ontario. Its name is derived from Monroe County, Michigan. In New York state only a part (chiefly the upper) of the Monroan series is present.

Falls (Fig. 1165), where at the American falls they form the floor of the "Cave of the Winds." The Lockport limestone (Fig. 1166) increases in thickness by the appearance of higher beds until at the Falls it is 80 feet thick (Fig. 1167), and 50 feet more are added in the rapids above the Falls. The higher beds are more

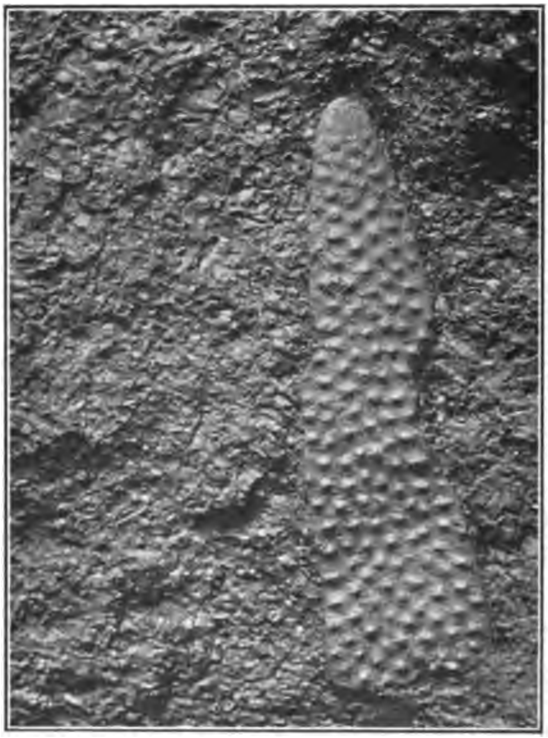


Fig. 1164. — Surface of a slab of red fossiliferous Clinton iron ore, Ontario, Wayne County, N. Y. The main mass of the rock consists of fragments of fossils replaced by iron ore, the large fossil is a fragment of a Bryozoan similarly replaced. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

dolomitic and in part represent the Guelph formation. Beyond this the beds are covered by drift, but from borings we know that they consist of soft shales and gypsum, constituting the Salina group which is without fossils. In the northern part of the city of Buffalo the higher of these beds are exposed in some places, and are followed by the Bertie group of shales and waterlimes (Fig. 1168 *d*, *e*). Fossils are rare in the Bertie except in certain

FIG. 1165. — View looking north, down the Whirlpool Rapids gorge, from West Grand Trunk Railway bridge. At the water level in the distant edge of the right-hand cliff the Whirlpool sandstone appears. Above it are the Medina sandstones and shales forming the lower slope. The Clinton limestones form the middle cliff of both banks, the Rochester shales (68 feet) the upper sloping bank, and the Lockport dolomites the upper cliff. (F. B. Taylor, photo; from U. S. G. S.)

FIG. 1166. — Wall of Niagara gorge below Suspension Bridge, American side, view from Canadian bank. The lower part of the cliff above the gorge road is formed of the Medina sandstone (red) capped by the white Thorold quartzite, here four and one-half feet thick, and shown as the lower white band in the cliff. Above this lies the Clinton Shale (9 feet or less) capped by the Clinton limestones which form a prominent cliff. The Rochester shale succeeds this, while the terminal cliff is formed by the Lockport limestone and dolomite. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

layers near the top, where the remarkable merostome *Eurypterus* and its allies (Fig. 1169) are found, often in great abundance and perfection of preservation. The remains of a few other organisms

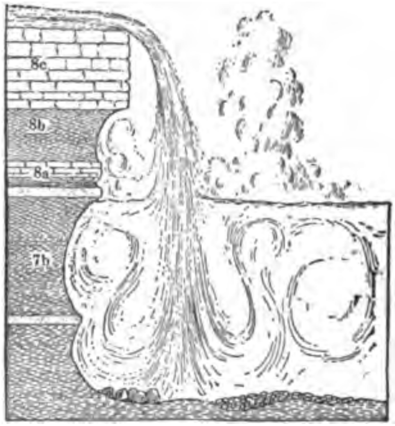


FIG. 1167. — Section of the Horseshoe Falls, Niagara, to show the arrangement of the strata; 7 *b*, Medina sandstones and shales with Whirlpool sandstone at base (resting on Queenston shales) and Thorold quartzite above; 8 *a*, Clinton shale and limestones; 8 *b*, Rochester shale; 8 *c*, Lockport dolomite. (After Gilbert.)

Fig. 1168. — Section in the Cement quarry, North Buffalo, N. Y. At the base is the Bertie waterlime with the cement bed (*d*) followed by the Cobleskill (Akron) dolomite (*c*). The surface of this layer is marked by erosion, and frequently by a layer of sand grains. Above it lies disconformably the Onondaga limestone (*b*) followed by the cherty beds (Corniferous limestone, *a*), both of Middle Devonian age. The disconformity can be traced across the view as an irregularity of contact. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

are also found. Above the Bertie waterlime appears a thin bed of dolomitic limestone, the Cobleskill (Fig. 1168 *c*), which is characterized by some small brachiopods, *Spirifer eriensis* (Fig. 1170 *a, b* etc.), a coral, the ostracod *Leperditia scalaris* (Fig. 1170 *f*), and

FIG. 1169. — Characteristic eurypterids of the Bertie waterlime. *a, Dolichopterus macrocheirus; b, Eurypterus lacustris.* (Both one-third natural size.)

some other types. The top of the Cobleskill shows a strong erosion surface upon which frequently lies a thin layer of quartz sand grains, followed by a thick bed of limestone (Onondaga) which is of Middle Devonian age (Fig. 1168 *b*). Thus there is

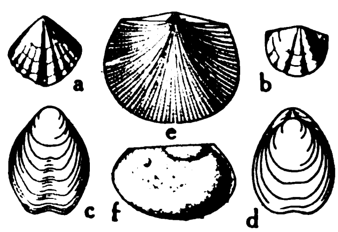


FIG. 1170. — Upper Silurian (Cobleskill) fossils. *a–b, Spirifer eriensis; c–d, Whitfieldella sulcata; e, Schuchertella interstriata; f, Leperditia scalaris,* left valve.

at this point a great break in the series. There is another break, though not well indicated, between the Salina and Bertie groups.

Section at Kingston, New York (Fig. 1171). — At Kingston, New York, on the banks of the Hudson River, the strata are folded and variably inclined. At the base of the section we find the

Cobleskill limestone lying unconformably upon the Ordovician shales and sandstones, the two differing markedly in dip, in some

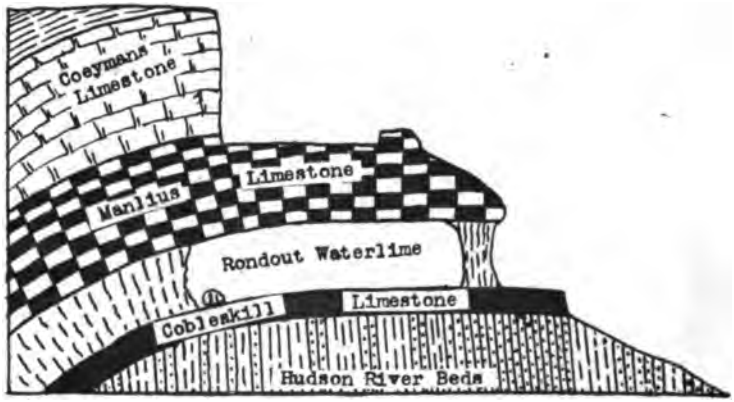


FIG. 1171. — Section at Kingston, N. Y., showing the Upper Silurian (upper Monroe beds, Cobleskill to Manlius) resting unconformably upon the Ordovician Hudson River beds and followed conformably by the Lower Devonian Coeymans limestone. (Original.)

sections being inclined at right angles to each other (Fig. 1172). Besides the fossils found in this rock at Buffalo there occasionally

FIG. 1172. — Unconformable contact between Hudson River sandstones (Ordovician), dipping steeply to the left, and nearly vertical Upper Silurian strata (Cobleskill limestone) resting against them. (See Figs. 527 and 528 *a, b*, pp. 609–611, Pt. I.)

occurs the coral *Halysites*. Above the Cobleskill follows the Rondout waterlime, formerly much quarried for natural cement (Fig. 1173), as was the Bertie below the Cobleskill at Buffalo.

FIG. 1173. — Disturbed Upper Silurian strata above Rondout, New York (Glory Hole section, Vlightberg), showing repeated overthrusts of folded strata of Rondout and Manlius limestones. The *Leperditia*, Prismatic and Paving block members lie between the cement rock (Rondout) and the typical Manlius. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

The Rondout is rarely fossiliferous, but includes layers characterized by mud-cracks (Fig. 1174). Then follows another series of fine-grained, thin-bedded limestones, the *Manlius*, 50 feet thick, and with comparatively few species of fossils, generally restricted to certain layers but occurring often in great numerical abundance. The most conspicuous are: the small, ringed and needle-like

FIG. 1174. — Prismatic layer in the Rondout waterlime, Upper Silurian (Monroan) of Kingston, New York. These prisms, which are seen on the under side of the overhanging ledge, represent mud-cracks in the old lime-muds, and indicate exposure to the air during their formation.

Tentaculites gyracanthus (Fig. 1175), one of the Conularida (p. 126), the small bean-shaped ostracod *Leperditia alta* (Fig. 1176), and the small brachiopods *Spirifer vanuxemi* (Fig. 1177) and *Stropheodonta*

FIG. 1175. — *Tentaculites gyracanthus* (conularid), Manlius limestone.

varistriatus (Fig. 1178). In some places also the subspherical hydrozoan colony, *Stromatopora*, is very abundant. The series is succeeded practically without break by the coarser-grained *Coeymans limestone*, the basal bed of the Helderbergian (Lower Devonian) series. Thus we have added two more formations to the top of the Silurian, above which follows conformably the Lower Devonian. The disturbed character of these rocks in some sections is shown in Fig. 1173.

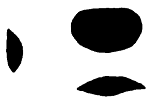


FIG. 1176. — *Leperditia alta* (ostracod), Manlius limestone.

FIG. 1177. — *Spirifer vanuxemi* (X 2), Manlius limestone.

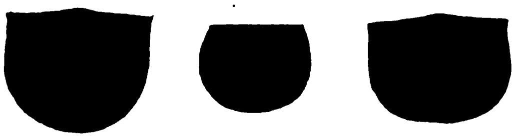


FIG. 1178. — *Stropheodonta varistriata*, Manlius limestone.

South of Kingston, a lower series of formations appears beneath the Cobleskill. Immediately below it lies a lower waterlime,

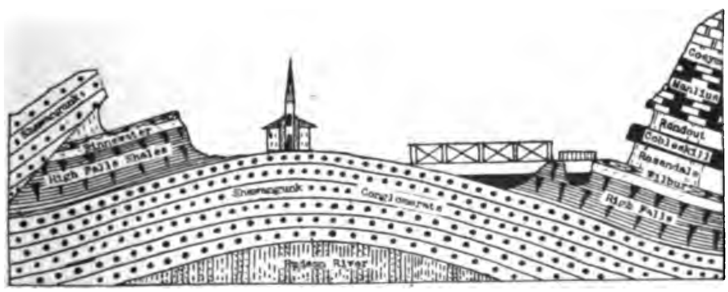


FIG. 1179. — Section across the pitching anticline at Rosendale, New York, showing the unconformable relation of the Shawangunk conglomerate to the Hudson River shales and sandstones, the succeeding lower Monroe (High Falls) shales, Binnewater sandstone (middle Monroe) and the upper Monroe limestones. The two waterlimes have here been extensively quarried. On the left the Shawangunk conglomerate is brought above the Rosendale by a thrust-fault. (Original.)

the *Rosendale* (Fig. 1179), and this rests upon a thin limestone, the *Wilbur*, which in turn overlies a quartz sandstone, the *Binnewater*, and underlying this we find a series of red and green shales

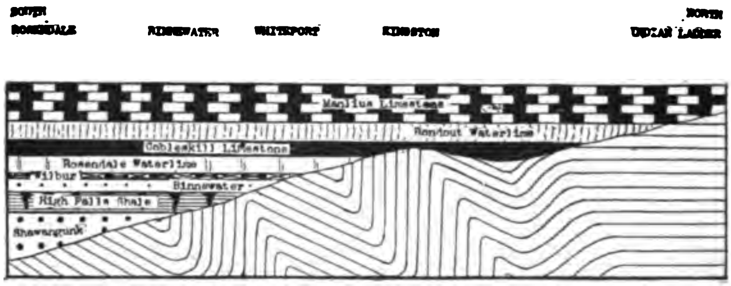


FIG. 1180. — Section from Rosendale, New York, to Indian Ladder, New York, showing the unconformable superposition of the Silurian beds upon the Hudson River series (disconformable in the north) and the overlap of the successive strata northward. (Original.)

and some thin waterlimes (*High Falls* series), these lying in turn upon a white quartz pebble conglomerate (*Shawangunk conglomerate*), the thickness of which increases southward until in the Shawangunk Mountains, from which it receives its name, it has reached 600 feet or more. The above section (Fig. 1180) shows the northward overlaps.

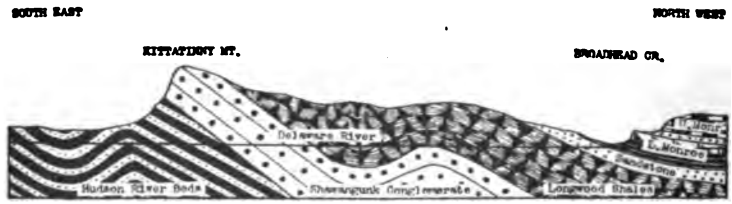


FIG. 1181. — Section at the Delaware Water Gap showing the very gentle unconformity between the Hudson River shales and the Shawangunk conglomerate which forms the main mountain ridge and is about 1500 feet thick. The succeeding Longwood shales, about 2000 feet thick, are red beds terminated by a sandstone member. The lower Monroe is represented by shales and limestones, the Sylvania horizon by a pebble bed, and the upper Monroe chiefly by limestones. (Original.)

Section at the Delaware Water Gap, Pennsylvania (Fig. 1181). — In this section the beds dip at a steep angle to the northwest and within the gap they show a series of small anticlines and synclines. At the gap and forming the crest of the high mountain ridges on each side is the Shawangunk conglomerate, about 1500 feet thick, resting with a slight unconformity upon the Ordovician shales and sandstones, a relationship also found elsewhere in that state and in parts of New York (Fig. 1182). In the conglomerate series are occasional thin beds of black shales which carry abundant remains of eurypterids, which are, however, generally fragmentary. Essentially the same eurypterid remains are found in black shales at the contact between the Guelph and the Salina in western New York (Rochester region), and the Shawangunk conglomerate is thus seen to represent essentially that horizon. The trail *Ar-*

FIG. 1182. — Unconformity between Shawangunk conglomerate (Silurian) and Hudson shale (Ordovician) exposed in railroad cut west of Otisville, N. Y. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

throphycus is also occasionally found. This conglomerate passes upward into a great series of red sandstones and shales about 2000 feet thick (*Longwood* beds). After a covered interval, the section shows a series of shales and limestones 350 feet or more in thickness, the limestones usually very fine-grained and with fossils in certain layers, most common among which are those found in the Manlius limestone elsewhere but ranging here through a greater thickness.

The beds thus represent only the Middle and Upper Silurian formations, the former being mostly continental (torrential conglomerates and red beds) and the latter fossiliferous limestones.

The Lower Silurian or Niagara is absent here, being overlapped by the higher divisions. These lower beds appear, however, in the Appalachian ranges farther west, as shown in the next section.

Sections across Appalachian Ridges. — Bald Eagle Mountain is the westernmost of the Appalachian ridges, extending through

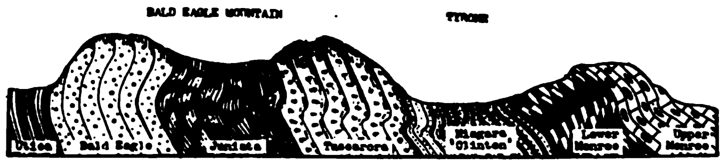


FIG. 1183. — Section of Bald Eagle Mountain, central Pennsylvania, a double ridge formed by the resistant sandstones and conglomerates with red beds between, each about 1000 feet thick. The Niagaran is mostly represented by shales and sands, the lower Monroe by thin-bedded ribbon limestones, and the upper Monroe by a massive coral limestone (Lewiston limestone). (Original.)

central Pennsylvania, and represents one of the erosion remnants of the Appalachian folds. Most of the formations shown in this ridge are also found in the other parallel ridges throughout the Appalachians, the sandstones generally forming the crests of the mountains.

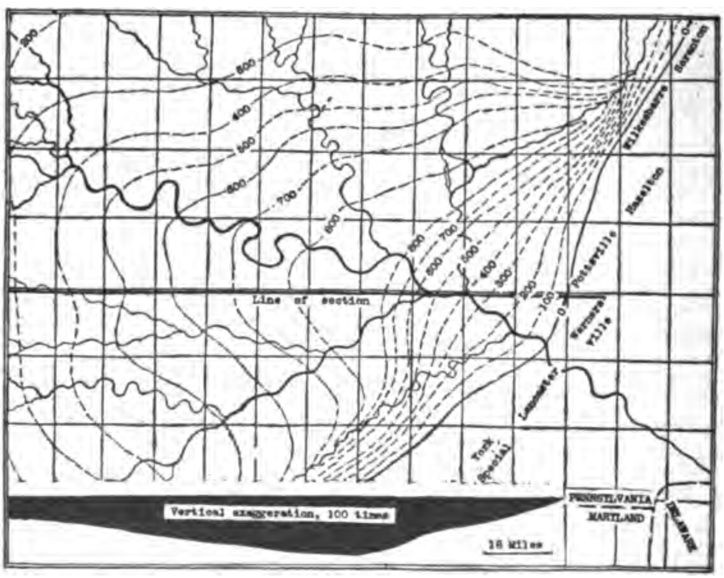


FIG. 1184 *a*. — Alluvial fan or delta formed of sands washed from Appalachia into the Appalachian trough and now constituting the Tuscarora sandstone of Pennsylvania, and Maryland. The contour-lines represent the thickness of the formation as originally deposited. The quadrangles represent the modern map-sheets of the region (U. S. topographic sheets). A cross-section (vertical scale greatly exaggerated) is shown in black. (Original.)

Resting conformably upon Upper Ordovician fossiliferous shale, and forming the first ridge, is a great conglomerate (*Bald Eagle*), about 1000 feet thick, which is followed by a series of red sandstones and shales (*Juniata*) of similar thickness. These represent the closing stages of the Ordovician and are comparable in part to the Oswego sandstones and Queenston shales of New York. Some-

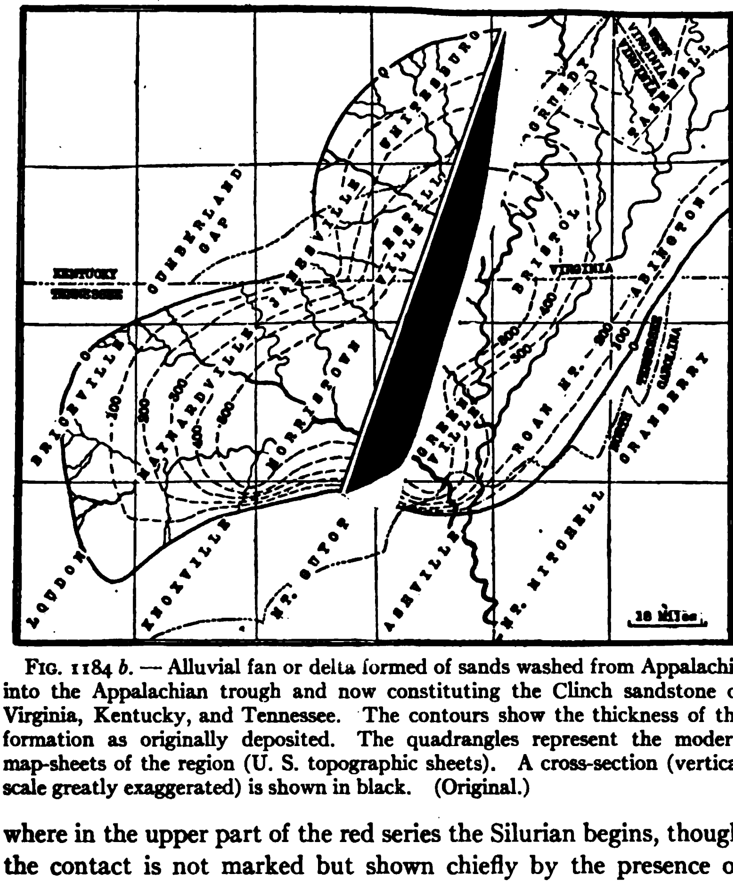


FIG. 1184 *b*. — Alluvial fan or delta formed of sands washed from Appalachia into the Appalachian trough and now constituting the Clinch sandstone of Virginia, Kentucky, and Tennessee. The contours show the thickness of the formation as originally deposited. The quadrangles represent the modern map-sheets of the region (U. S. topographic sheets). A cross-section (vertical scale greatly exaggerated) is shown in black. (Original.)

where in the upper part of the red series the Silurian begins, though the contact is not marked but shown chiefly by the presence of *Arthrophycus harlani* (Fig. 759), etc. The next succeeding sandstone, the *Tuscarora*, also about 1000 feet thick, is of early Silurian age and is traceable widely over the Appalachian Mountains, as it is one of the chief crest-makers. In Virginia this rock goes by the name of *Clinch sandstone*, from the mountain of that name which it forms (Fig. 752). These sandstones are erosion remnants of what was originally a series of more or less confluent delta-like deposits built westward from Appalachia into the Appalachian trough, and the westernmost thin edge of which is represented by the Thorold quartzite of the Niagara section (Fig. 1184 *a*). Upon the Clinch follows a series of shales and sandstones, often with fossils and with one or more beds of iron ore. In the southern

FIG. 1185. — Upper Silurian coral and Stromatopora reef-limestone (Lewiston limestone), Tyrone, Pennsylvania.

Appalachians this formation is called the *Rockwood*. It represents the shallow water marine equivalent of the Clinton and part of the succeeding beds of the Niagara section. Then follow more shales and sandstones, some of them red, Salina and Monroe, and the section is terminated by a great limestone series, — the lower part fine grained and with few fossils, the upper coarser grained and abounding in fossils, most common among which are stromatoporas and corals (Fig. 1185). This highest division is called the *Lewiston* (*Keyser*) *limestone*, and it is followed by beds of Helderbergian age (Lower Devonian), the succession being uninterrupted.

Interpretation of the Sections

Taking these and numerous other sections of the Silurian in North America as the basis of our interpretation of the history, we are able to deduce the following general facts.

Lower Silurian. — In the central areas (Wisconsin, Michigan, Ohio, etc.) the Lower Silurian or Niagaran is wholly marine and mostly limestone, resting disconformably upon the older rocks, with in some cases (eastern Wisconsin) an oölitic iron ore at the base. As we approach the Appalachian trough we find shales and sandstones partly replacing the limestones, especially in the basal part (Medina). These sandstones increase in thickness eastward until they assume the character of great sand deltas (Tuscarora, Clinch), while the succeeding beds are mainly shales and sandstone, limestones being very rare in the series in the Appalachian trough. From this we draw the following conclusion: In Lower Silurian (Niagaran) time the Appalachian trough was plentifully supplied with sands and muds by streams entering from Appalachia. These streams at first built a series of sand deltas (Fig. 1184), and later deposited chiefly muds and some sands. The sand delta deposits contain no fossils (except the trail *Arthrophycus*), which shows that normal sea water was kept out from the more easterly parts of the trough. The presence of marine fossils in the higher mud deposits indicates that in the later stages the subsidence was sufficiently rapid to permit the sea to enter this part of the trough as well. Meanwhile the interior of the country was covered by the sea and in those parts into which the mud deposits from Appalachia did not extend, pure limestones only were formed, these being in many cases due to the abundant growth of corals and stromatoporas. Many old reefs or reef-like accumulations have been discovered in this series, especially in Wisconsin, Michigan, Ohio, and Indiana, the most famous being the one at the Falls of the Ohio near Louisville, Kentucky, which region has furnished an abundance of finely preserved (usually silicified) Niagaran corals. This leads to the conclusion that the waters of the interior seas were warm and pure, with an abundant development of life.

Midway between the zones of abundant sand and mud deposits in the east and the zone of pure limestone formation in the interior was the zone of transition, where at one time sands and muds, at another time limestones, were forming, owing to the oscillatory nature of the sea-bottom. As certain species of animals, such as corals, live only in pure water, these are confined to the limestones. Other types of animals (brachiopods, etc.), which can live in muddy waters as well, are found both in the shales of the central and

FIG. 1186. — Palæogeographic map of North America, showing the distribution of land and sea (black), in early Niagaran time. (Original.)

eastern region and in the limestones formed at the same time farther west, while still others are restricted to the shales.

A careful study of the character and distribution of the fossils shows further the following facts. There were at least three centers of origin from which the organisms invaded the interior sea. The most important of these faunal centers was the northern one, apparently the region of the present Arctic, which was then the center of coral growth and therefore a warm water ocean. Corals then grew abundantly not only over Michigan, Wisconsin, and Canada, but also in the American Arctic region and on the other side of the earth in Siberia in regions now lying within the Arctic Circle. The similarity of the corals on both sides of the earth suggests that free communication existed across the present Arctic between North America and northern Asia, from which, as we shall see, arms extended into Europe.

A second faunal province appears to have been the southern Pacific, from which the organisms entered the epeiric seas which then covered North America by way of the southern end of the Appalachian trough, and spread westward and northward whenever the conditions permitted. Now it is perfectly possible to determine the characteristics of this fauna by noting what it was like before there was any intermingling with species from other sources. Fortunately the oldest Silurian deposits in the southern Mississippi Valley were of a limited extent, and because they are restricted to that area and their several beds overlap northward, it is seen that they were formed in an embayment from the south (Fig. 1186). This fauna consists of small, flat-shelled brachiopods (*Schuchertella*, etc.), smooth-shelled, convex brachiopods (*Whitfieldella*), small plicated brachiopods (*Homœospira*, etc.), small pelecypods and gastropods, and other types (Fig. 1170). From the small size and general appearance of the organisms, it is hard to escape the conclusion that they were derived from a source which, on the whole, was unfavorable to the development of many and complex species, and the most ready interpretation seems to be that the waters of the southern Pacific at that time were colder than those of the Arctic, though this is by no means proved to have been the case.

A third faunal province was the Atlantic Ocean, the animals from which entered the interior of North America by the northern end of the Appalachian trough, which was then in communication with the Atlantic. As might be supposed, many of the species of this province are also found in the rocks of western Europe, especially in England, because that region also communicated with the Atlantic. This fauna is most abundant in the rocks of Anticosti Island in the Gulf of St. Lawrence, which island preserves a remnant of the sea bottom of that time, near the northern end of the Appalachian trough. The deposits in the other parts of the Appalachian trough also contain these species, somewhat mingled with those entering from the northwest and from the south. This Atlantic fauna also migrated westward to some extent into the region occupied by the coral fauna, and the fossils of the Clinton limestone show this westward invasion most completely. On this account the fauna is sometimes spoken of as the Clinton fauna, but the beds carrying it in the east are much

FIG. 1187. — Diagram illustrating the relationships of the principal faunas in the Niagaran rocks of North America. The "Clinton" fauna with *Pentamerus oblongus*, *Cœlospira hemisphærica*, etc., on the east (shown in black) entered from the Atlantic; the Niagara or Boreal fauna on the west (in white) with *Halysites*, *Favosites* and other corals and with distinctive brachiopods, etc., came from the north. The Niagaran strata on the west contain mainly this coral fauna except for the basal portion in which the "Clinton" fauna occurs. On the east the Niagaran beds are chiefly occupied by the "Clinton" or Atlantic fauna. Between the two an intermediate or mingled type is found in the Rochester shales. (Original.)

more extensive and cover a greater time interval than the Clinton beds of the Niagara section. The section (Fig. 1187) shows the east-west relationship.

There was another area of Niagaran deposition, namely, in the Cordilleran geosyncline, but the formations there have been little studied. It is known that at the close of the Ordovician the Siberian Silurian fauna, with its corals and other types, had entered this trough, forming an advance invasion, while the late Ordovician (Richmond) fauna apparently still lingered in the interior. In some sections black Niagaran shales with *Cyrtograptus* (Fig. 1205) rest disconformably upon similar Lower Ordovician shales with *Phyllograptus* (Fig. 1070), but the relationship of these deposits to those of other regions is still unknown. In Alaska some evidence of glacial conditions in Silurian time has recently been discovered. Some of the stages in the development of the Niagaran epeiric seas are shown in the palæogeographic maps (Figs. 1186, 1188).

FIG. 1188. — Palæogeographic map of North America, showing the distribution of land and sea (black) in late Niagaran time, when the sea had attained its maximum extent. (Original.)

It is now plain why, in different parts of our country, the Niagaran series is not only represented by different types of sediments, but also why different assemblages of organisms exist in different parts. By the confluence of the several invading waters, an opportunity for commingling and for further development of the several faunas was furnished.

The Middle Silurian or Salinan. — Throughout the Appalachian region of New York and Pennsylvania the Middle Silurian or Salinan is represented by continental deposits, partly quartz-pebble conglomerates, but largely red beds (shales and sandstones). South of Maryland the Salina beds are absent, fossiliferous Upper Silurian or Monroan beds resting disconformably upon the Niagaran strata. They, however, sometimes include sands and clays which were originally deposited during the Salina period, but were reworked by the advancing Monroan seas, and from their red color may be mistaken for Salina sediments. In central and western New York, in northern Ohio, in Michigan, and in parts of Ontario, the Salina is represented by shales and lime-mud beds (calcilutytes) which inclose extensive rock salt deposits amounting in the aggregate to many hundreds of feet of rock salt. In some sections the lime mud-rocks have been altered to gypsum by sulphuric waters, but original gypsum or anhydrite deposits are exceedingly rare, and when they occur they do not occupy the normal position beneath the salt beds that is found in salt deposits of oceanic origin. In New York state an extension of the red beds (*Vernon shale*) generally underlies the salt series, but this dies away westward as is to be expected in a deposit which was derived from the east. Both the salt and the red beds indicate arid conditions during this period.

What, then, was the source of the salt? We have seen that the absence of gypsum or anhydrite beds beneath the salt negatives a marine origin, for, as has been explained (p. 234, Pt. I), in normal marine salts each salt bed should be preceded by a bed of gypsum or anhydrite. Furthermore we have seen that salt deposits formed in lagoons in frequent connection with the sea should be characterized by layers of sediment rich in organic remains; but organic remains are conspicuously absent from the Salina deposits. Again, it has been shown that when salt deposits are formed in a lagoon or in a permanent cut-off from the sea, there are present somewhere, not too distant from the salt deposits, normal marine conditions under which normal marine fossiliferous sediments are deposited. But nowhere on the whole continent of North America are there any marine Salina deposits known, and although such deposits were undoubtedly formed in the oceans of the time, these

FIG. 1189. — Palæogeographic map of North America, showing the distribution of land and sea (black) at the close of Palæo-Silurian (Niagaran) or opening of Meso-Silurian time. The Shawangunk delta or alluvial fan was deposited by the rivers of Appalachia; the interior lagoons were sometimes fresh-water lakes, sometimes salt-water bodies, when the sea broke across the barriers. This stage was followed by the complete drying up of the interior waters, and the formation of the Salina desert, in which the red beds, and salt deposits accumulated. (Original.)

oceans were too far removed from the region of salt deposition to permit communication with it. If there had been communication, its path should be marked by fossiliferous marine Salina deposits. But, as stated, these are unknown, nor could these deposits have been wholly removed by subsequent erosion, because there are too many localities remaining around the salt area where Upper Silurian (Monroan) beds rest directly upon the Lower Silurian (Niagaran), the contact being marked by an erosion plane. In the salt area, however, the marine Upper Silurian beds rest upon the Salina beds, thus clearly indicating that the sea returned after the deposition of the Salina strata.

Reviewing all the sections, the following history is indicated. At the end of Niagaran time the sea withdrew from the North American continent. Deposits of pebble beds were formed in the Appalachian trough by rejuvenated rivers from Appalachia as a result of the elevation of the land which caused the withdrawal of the sea (Fig. 1189). These pebble beds now constitute the Shawangunk conglomerate.[1] Then conditions changed to aridity, probably as the result of continued elevation of the mountains of Appalachia, which shut out the moisture-bearing winds from the Atlantic — the prevailing winds of the time. The intermittent streams from Appalachia continued to build alluvial fans into the now dry Appalachian trough. These deposits were formed at such intervals that thorough oxidation of the iron disseminated in them could take place. As a result these beds are to-day (after long burial, dehydration, and subsequent resurrection by erosion of overlying beds) typical red beds. The finer muds of these oxidized deposits were spread over parts of the interior (New York, Pennsylvania), probably by the wind, forming a sort of loess-like deposit, as in modern deserts. Thus were formed the fine, uniform, and structureless red shales found in some sections (Vernon red shale of New York, Bloomsburg shale of Pennsylvania).

Meanwhile, the elevated Niagaran limestones everywhere were undergoing disintegration. As these had but just been raised above sea-level, they were rich in enclosed connate sea-water and sea-salt. This was set free on disintegration of the enclosing limestones and, under the arid climate, accumulated as a salt

[1] As this conglomerate apparently accumulated in the east while the Guelph dolomites were accumulating farther west, it may with propriety be referred to the closing stages of the Niagaran instead of the opening stages of the Salinan as is generally done.

efflorescence. Occasional rains dissolved this superficial salt crust, and carried the salt in solution into the deeper-lying basins of the region (New York, Michigan, Ontario, Ohio), where, by evaporation of the water, the salt was left behind as it is in modern deserts. Whenever the other products of disintegration of the limestone were washed or blown into these basins, layers of lime-mud covered the salt beds, to be in turn succeeded by other salt beds. Subsequent alteration changed some of these lime-mud deposits to gypsum, but original gypsum was not ordinarily deposited, except as scales and crystals in the silt and sand around the salt lakes,

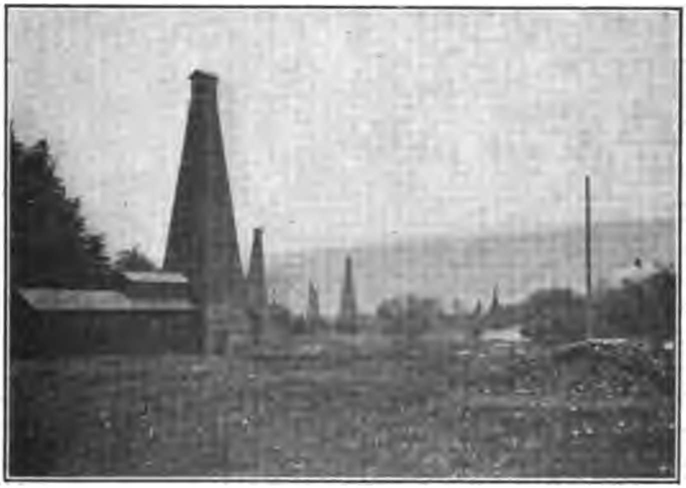


FIG. 1190. — Salt wells in the Salina formation in the Tully Valley, south of Syracuse, N. Y.

where they are found to-day. At the close of the Salina period the seas again advanced on this continent, and their deposits were spread alike on the Salina beds and on the eroded Niagara beds which surrounded the Salina basins.

It is thus clear that all the characters of the Salina deposits and their relation to the other formations point to accumulation in interior basins not in communication with the sea. The salt is thus of connate origin, being in large measure the sea-salt inclosed in the Niagaran rocks while they were forming on the bottom of the Lower Silurian sea. These deposits constitute one of the most important sources of salt in the United States, the mineral being obtained both by mining and by underground solution and pumping of the brine to the surface. Evaporation of the brine is largely effected by artificial heat (Figs. 1190, 1191).

The Upper Silurian or Monroan. — In southern Michigan and the adjoining districts, where the Salina formation is developed in its full thickness and where the most extensive beds of rock salt known in that formation occur, we also find the best preserved series of Upper Silurian rocks, the Monroan. This has an aggregate thickness of a thousand feet, and consists of two main divisions

FIG. 1191. — Syracuse salt works. The salt is obtained from the Salina brines, and separated both by solar and artificial evaporation.

of limestones and dolomites, separated by a pure quartz sandstone, the *Sylvania*. This sandstone indicates a period of emergence and the accumulation upon the exposed surface of quartz grains, apparently derived from the erosion of the older St. Peter sandstones. These grains are wonderfully well rounded and of remarkable uniformity of size, while grains of other minerals are wholly wanting, making this an ideal rock for the manufacture of glass (Fig. 361, p. 440, Pt. I). The thickness of the sandstone, which reaches in places 150 feet, its areal extent, the strong eolian cross-bedding as well as the detailed characters of the grains above mentioned, indicate that the period of exposure which it represents and which fell between the deposition of the lower and the upper Monroan formations was long, and its importance is further indicated by the great contrast between the organic remains which are found in the lower and in the upper Monroan beds.

FIG. 1192. — Palæogeographic map of North America in early Neo-Silurian (lower Monroan) time, showing the distribution of land and sea (black).

When we trace the distribution of the lower Monroan beds over North America, we find them restricted to the southern parts of the Appalachian trough, as far north as New Jersey, whence they extend westward over Pennsylvania, Ohio, Michigan, and Wisconsin. They are also known from a few localities in New York state. Wherever the Salina beds are present, these lower Monroan beds rest upon them, but in all other localities they rest upon the eroded surfaces of the Niagaran or older rocks. The map (Fig. 1192) shows the extent of the lower Monroan sea, and the areas where its deposits rest upon Salinan rocks. It also shows, what is clearly indicated by the distribution of the formations, that this sea was an invasion of the continent from the Pacific on the south.

The organic remains of this division are uniformly of types which suggest rather unfavorable conditions of existence. Corals appear to be absent altogether, while the brachiopods which occur are of the small types, very similar to those which we found to be characteristic of the southern Pacific fauna in early Niagaran time. It is indeed, in a sense, this early southern fauna, modified somewhat in the course of time, which has returned. Besides the small brachiopods (*Whitfieldellas*, small *Spirifers*, etc.) and some small pelecypods, small bivalve crustacea of the group of ostracods (*Leperditia*, *Klœdenia*, etc.) are very abundant, and often constitute a leading element of the fauna.

When we examine these Monroan limestones, we find that they have certain very striking characteristics. In composition they are often dolomitic. They are almost always thin-bedded, resembling much more in their structure deposits of fine sand or mud than they do limestones of organic origin. The fossil shells which they contain are practically always unbroken, and occur in layers, sometimes forming thin beds, but more generally scattered over the bedding planes after the manner of occurrence of fossils in beds of shale or other mud-rocks. Hence the lime which constitutes the mass of the rock could not have been derived from such fossils, but must be regarded as a deposit of lime-mud and sand, in which the fossils were included as foreign bodies. Some of the fine lime-muds are of proper composition and texture to produce natural cements. Coral or nullipore reefs or great shell accumulations, from which by erosion the lime-sand and lime-mud of this series could have been derived, are wholly unknown in the lower Monroan series; therefore the lime could not have been manufactured by organisms in lower Monroan time. There is, however, an exception to this in the presence in the higher part of the series of several beds of oölite which are either the product of bacterial activity in the sea (see p. 270, Pt. I) or were produced by the growth of minute lime-separating algæ. These beds, however, make up only a small part of the series, and the great mass of lime-sand and mud must still be accounted for.

When we recall that during Salina time the Niagaran and older limestones were everywhere exposed around the salt-basins to the disintegrating effects of a dry climate, we realize that, as a result of this disintegration, vast quantities of lime-sand and lime-mud must have been produced from which the salt had been leached, and carried to the central basins. It is therefore an obvious inference that these residual lime-sands and muds were encountered by the transgressing Monroan sea, the waves and currents of which spread it out more or less uniformly over the surface in regularly stratified layers. This, indeed, appears to be the only tenable explanation of the origin of these deposits.

In the Appalachian trough, muds derived from Appalachia were deposited and here the lower Monroan beds are often shales. During Salina time, it will be remembered, thoroughly oxidized sands and muds were deposited in the northern part of the trough, these being to-day red beds. Whenever the encroaching lower Monroan sea encountered such oxidized material, which had not yet become consolidated, part of it was reworked and incorporated in the sediments of that sea. Such oxidized sands and muds, when washed into the sea, remain in the state of oxidation unless there is an abundance of decaying organic matter on the sea-bottom which can act as a reducing agent, a condition which did not exist in Monroan time. Long after deep burial under other strata, such oxidized beds will turn red because the iron loses its water, and so we can readily understand the presence of red beds in certain parts of the lower Monroan series of the Appalachian region. These are found in Maryland (Fig. 500, p. 591, Pt. I) and in New York (upper *High Falls shales*, Fig. 501, p. 591, Pt. I). From their similarity to the red beds of the Salina series (*Longwood*), these secondarily reworked red beds of the lower Monroan have sometimes been erroneously identified as of Salina age.

At the end of lower Monroan time the sea retreated from a considerable part of the country but probably lingered in the southern part of the Appalachian trough. Over part of the exposed area the Sylvania dune sands were formed, while in portions of the Appalachian trough river-borne sands accumulated and these in some cases contain the remains of fishes, which at that time were apparently still confined to the rivers of the earth.

Upper Monroan time opened with the readvance of the sea, but this readvance was not only from the south, but also from the Atlantic in the northern end of the Appalachian trough and from the Arctic region over the interior of North America (Fig. 1193). The advancing waters from the south brought with them essentially the same organisms which characterized the lower Monroan deposits, while the advancing sea from the Arctic regions brought with it a new fauna, developed from the Niagaran fauna during the long interval between Niagaran and upper Monroan time. Corals were still common in this sea, and coral reefs once more began to form wherever these northern waters spread. Such coral and *Stromatopora* reefs are known from Michigan, Pennsylvania (Lewiston limestone, Fig. 1185), and to some extent from Maryland and Virginia. The Cobleskill limestone of New York marks an extension of the reef fauna, though it seldom represents reef conditions. It will be observed that these waters spread more widely than did those of the lower Monroan. In western and central New York the upper Monroan beds (Bertie waterlime series, Cobleskill) rest upon the Salina by overlap (Fig. 1146); at Schoharie the Cobleskill rests upon an old residual clay (Brayman, Fig. 537 p. 616, Pt. I), probably formed by decay of Ordovician rocks. At Kingston the Cobleskill rests on folded and eroded Ordovician sandstones (Fig. 1172).

The Cobleskill fossils include many corals of the types which characterized the upper Monroan of Michigan, the fauna of which came from the north. Hence we conclude that during the deposition of the Cobleskill limestone, the northern waters with their coral faunas spread eastward over New York and central Pennsylvania. But the Cobleskill is followed in New York and elsewhere, after an interval of waterlime deposition, by the Manlius limestone, and this has almost the same fauna as the lower Monroan beds of Michigan and of the Appalachian trough. Hence we must conclude that towards the close of Monroan time the southern waters again spread more widely in the Appalachian trough, bringing with them the persistent southern fauna of small brachiopods, *Leperditias*, pelecypods (Fig. 1194) and *Tentaculites*. At the same time the northern fauna held sway in the interior and here the highest Silurian beds contain very different fossils, but these fossils are remarkably similar to those found in the Upper Silurian rocks of northern Europe, showing intercommuni-

FIG. 1193. — Palæogeographic map of North America in late Neo-Silurian (upper Monroan) time, showing the distribution of land and sea (black). At that time there were three main oceanic invasions, the northern or Siberian, the southern or South Pacific, and the eastern or Atlantic, with a fourth, from the North Pacific, of which little is known. (Original.)

cation apparently across the Arctic between Europe and America.

Finally, the Upper Silurian rocks of the northern end of the Appalachian trough (Nova Scotia, etc.) carry essentially the fauna found in the Upper Silurian rocks of England; that is, the fauna which at that time lived in the Atlantic. Thus the Upper Silurian of central and eastern North America is characterized by three district faunas which existed side by side but in different geographic areas. The Atlantic fauna occupied the northern end of the Appalachian geosyncline; the southern or Pacific fauna occupied the southern area and extended up the Appala-

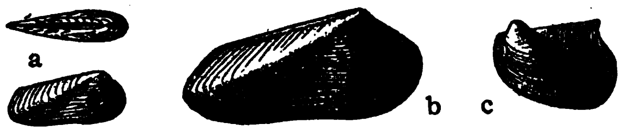


FIG. 1194. — Monroan pelecypods (southern types). *a–b*, *Goniophora dubia*: *a*, right valve and top view; *b*, right valve enlarged; *c*, *Pterinea lanii*. Left valve.

chian trough into eastern New York and northward, until it mingled with the Atlantic fauna, and westward until it met the northern fauna which existed in its purity in Michigan and farther north, and which at one time spread eastward to New York and New Jersey, as is shown by the distribution of the Cobleskill limestone. In addition to these three marine faunas there was the fauna of the Bertie and other waterlimes which consists almost entirely of eurypterids and which is thought to represent the fauna of the rivers of that period.

Europe and Asia

We know that coral reefs grew in early Silurian (Niagaran) time in the Siberian basin, and the similarity of these corals to those of central North America shows connection of the waters across the present Arctic region. From the Siberian basin an arm extended westward, joining the Baltic trough or geosyncline. In this trough coral reefs also grew, the best examples preserved to us being found on the Island of Gotland, off the coast of Sweden (Fig. 1195). These corals are mainly of the same types as those found in central North America. Farther west in the Baltic trough, great deposits of clastic material, chiefly muds, were accumulating, brought there by rivers from Atlantica, the continent on the northwest. In these muds, which were largely deposited in very shallow water as parts of deltas at the mouths of rivers (Fig. 1196), many grapto-

FIG. 1195. — Silurian coral reef on the island of Storo Karlsö near Gotland, Sweden. (Photo by Miss Mary Johnson.)

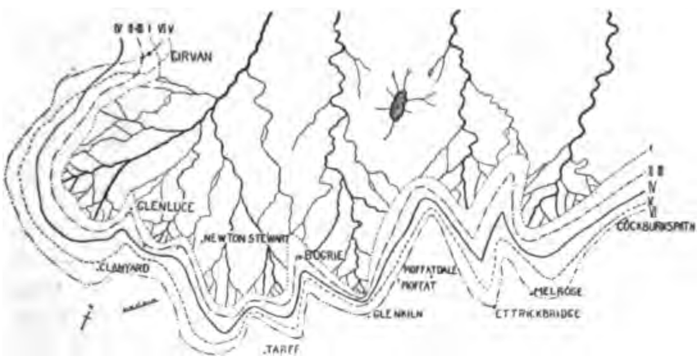


FIG. 1196. — Map of a fossil delta of early Silurian time in southern Scotland. The map was constructed by plotting the points at which six successive graptolite-bearing shale beds intersected unfossiliferous, continental sands washed into the sea by rivers. I, represents the locus of the final occurrences of the graptolites of the lowest zone, II, that of the final occurrences of the graptolites of the next higher zone, and so on. It will be seen that the continental, river-borne sands were spread out southward and that the sea retreated from shore-line I to shore-line VI as indicated by the southward off-lapping of the successive marine shale zones. On account of the profound folding to which the Silurian rocks of Scotland have been subjected, the map has been enlarged twice at right angles to the strike, which is northeast-southwest, in order to give approximately the conditions before folding; therefore it reads true for present geographical positions only along the strike. (Constructed and drawn by M. O'Connell.)

lites were included, especially of the *Monograptus* types (Fig. 1204). Such deposits are now found in Wales, northern England, and southern Scotland. Farther out in the more open waters of the trough more calcareous muds and even limestones (*Wenlock limestones*) were formed, and these contain many brachiopods, besides many of the corals of the lower Gotlandian beds. The English Silurian deposits, the type of the Silurian, contain chiefly the fauna from the

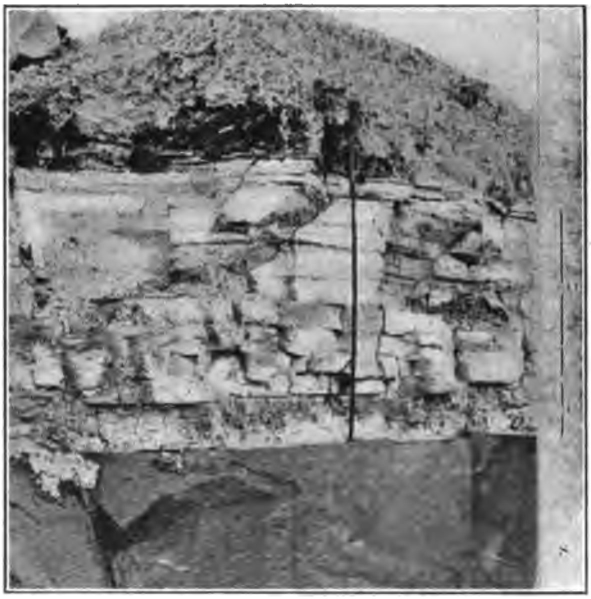


FIG. 1197. — Section in the Grindstone quarry near Gansvicken, Island of Gotland, showing the Gansvick sandstone (used for making grindstones) at the base, sharply and disconformably overlain by clay (C) and Oölite (O) of Upper Silurian age. The sandstone partly occupies the hiatus between the Lower and Upper Silurian (Gotlandian). (Photo by Holm from Munthe.)

Atlantic on the west mingled, however, with some of the organisms from the Siberian region on the east, while the Gotland deposits contain chiefly the Siberian fauna, which is also the North American fauna. Between the two in southern Norway there is a remarkable mingling of the faunas which often alternate in successive beds.

The Lower Silurian (Niagaran or Lower Gotlandian) series of Europe does not everywhere begin with the same formations. Moreover, it almost always rests upon an erosion surface either on Ordovician beds or on older strata, even on the crystallines.

This indicates an initial transgression of the Silurian sea with overlap of the several members, until much more of Europe was covered than was the case in Ordovician time. There, too, as in America, the wide spreading of the sea is followed by its retreat, and practically all the region once covered by the sea again emerged and became subject to erosion. This was in Middle Silurian or Salinan time. In a few localities (south Gotland, etc.) sands accumulated during this period of emergence (Fig. 1197), but on the whole the country was characterized by erosion rather than deposition, and the product of erosion was largely carried away instead of accumulating *in situ* as was the case to a considerable extent in North America. From this we conclude that the climate

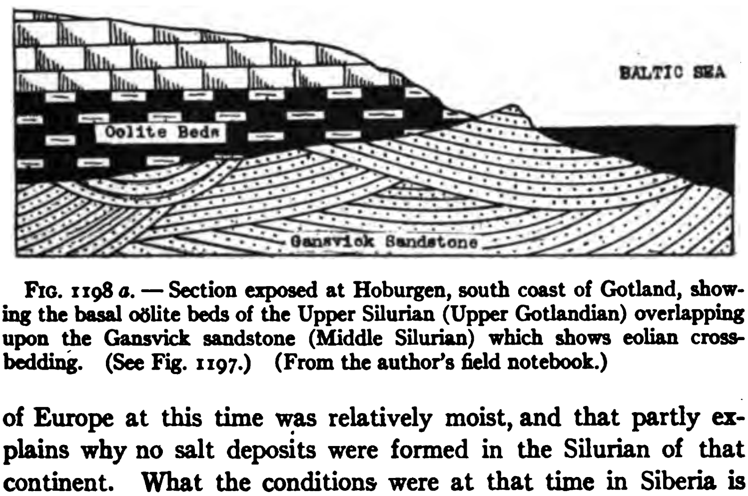


FIG. 1198 *a*. — Section exposed at Hoburgen, south coast of Gotland, showing the basal oölite beds of the Upper Silurian (Upper Gotlandian) overlapping upon the Gansvick sandstone (Middle Silurian) which shows eolian cross-bedding. (See Fig. 1197.) (From the author's field notebook.)

of Europe at this time was relatively moist, and that partly explains why no salt deposits were formed in the Silurian of that continent. What the conditions were at that time in Siberia is still unknown.

With the return of the sea in Upper Silurian time, renewed deposition of limestones in the interior of the basins and of clastic material along their margins took place. Because of the erosion interval, we find nearly everywhere the Upper Silurian strata resting disconformably upon the Lower (Fig. 1198). By this time the faunas had become modified, but there was still a Siberian fauna which characterized the Upper Silurian deposits of Gotland as well, where reefs were again built by the coral polyps (Fig. 1199). This Siberian fauna is also represented in the Upper Monroan of interior North America. There was, further, the Atlantic fauna which is typically represented in the upper Ludlow rocks of Engmost modified during the interval, those of the Atlantic to a less degree, and those of the Pacific least of all. Finally, towards the close of the Silurian, continental sediments again spread in northern Europe, while in North America widespread emergence took place.

Volcanic manifestations seem on the whole not to have been very pronounced during the Silurian although the volcanic rocks

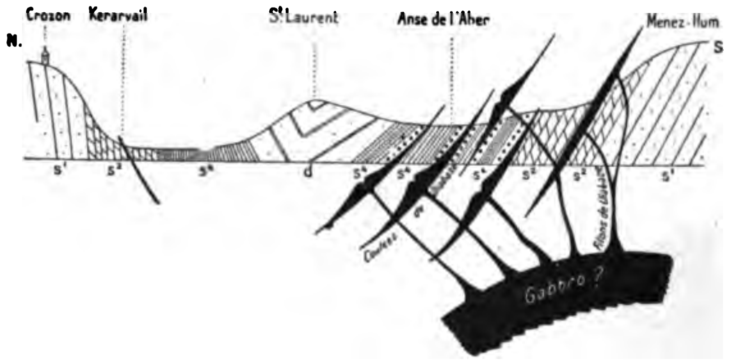


FIG. 1201. — Reconstruction of the Ordovician and Silurian volcanoes of Menez-Hom, Finistère. (After C. Barrois.) s^1, Armorican sandstone; s^2, Upper Ordovician; s^4, Gotlandian (Silurian); *d*, Devonian. (Haug.)

of New Brunswick, Nova Scotia, and Maine appear to belong to this period. In parts of France (Finistère), the volcanic phenomena of the Ordovician continued into the Silurian (Fig. 1201). In Bohemia, too, diabase beds are intruded with the Lower Silurian (Niagaran) beds.

Disturbances at the End of the Silurian

North America did not suffer any violent disturbances, so far as is known, at the end of Silurian time, although renewed elevation of many of the low domes and depression of the basins took place, together with the formation between adjoining basins or domes of more strongly pronounced anticlines and synclines. The domes and anticlines suffered erosion during the succeeding period, so that the later Devonian beds come to rest upon different older formations in different sections. In western Europe, however, an extensive period of folding closed the Silurian, forming the ancient Caledonian range of mountains which extended through Scotland and Ireland, where the Devonian strata rest unconformably upon the Silurian and older beds, while in Scandinavia great overthrusts took place, accompanied by igneous activities. Similar folding occurred in France, but in central Europe no disturbances are known. The Caledonian range is thought to have been much more lofty than the Alps before it suffered nearly complete truncation by erosion. In Asia the margins of the old Irkutsk basin of Siberia were folded into a semicircular mountain chain, while a new geosyncline came into existence in what was formerly a part of the oldland, and in this the succeeding marine strata were deposited (Fig. 1005, p. 216). The north Siberian basin itself had apparently become fully emerged and was not submerged again until Mesozoic time. Continental deposits of late Palæozoic age were, however, formed in it.

General Characters of the Silurian Faunas

There are certain respects in which the Silurian fauna differs quite markedly from that of the Ordovician period. Several remarkable **sponges** occur, such as the concavo-convex *Astræospongia* (Fig. 1202), and the nearly spherical

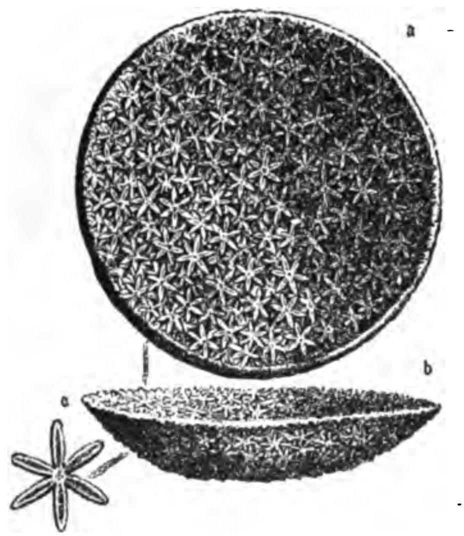


Fig. 1202. — *Astræospongia meniscus*, with enlargement of spicule. (I. F.)

Astylospongia (Fig. 1203). The **graptolites** are chiefly of the uniserial type with the cups or thecæ arranged on one side of the supporting axis or virgula (*Monograptus*, Fig. 1204; *Cyrtograptus*, Fig. 1205; *Rastrites*, Fig. 840 *c*, etc.). The biserial graptolites have become highly modified (*Retiolites*, Fig. 1155). **Corals** are abundant, in the limestone, *Favosites* (Fig. 1162) mak-

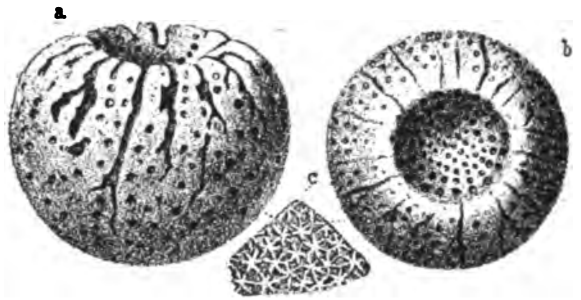


FIG. 1203. — *Astylospongia præmorsa*, with enlarged section. (I. F.)

FIG. 1204. — *Monograptus priodon*, a Lower Silurian (Wenlock — Lower Ludlow) European graptolite. (K.) See also Fig. 1154, p. 318, for the related American form.

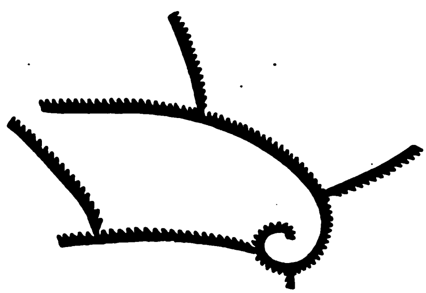


FIG. 1205. — *Cyrtograptus murchisoni*; a characteristic Lower Silurian (Niagaran) graptolite, Europe, etc.

FIG. 1206. — *Syringopora verticillata*, a characteristic Silurian (Niagaran) tube-coral.

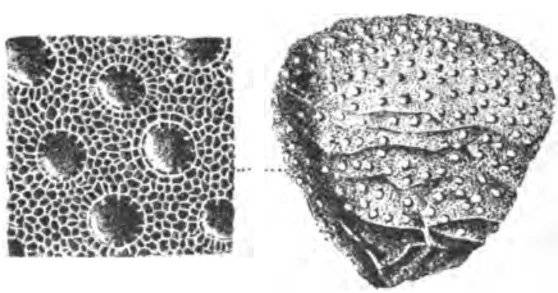


FIG. 1207. — *Heliolites interstinctus*, with part of surface enlarged. A characteristic Niagaran coral of the interior. (I. F.)

FIG. 1208. — *Omphyma subturbinatum*, a European Lower Silurian (Wenlock) coral. (K.)

FIG. 1209. — *Goniophyllum pyramidale*, a European Lower Silurian (Wenlock) coral. (K.)

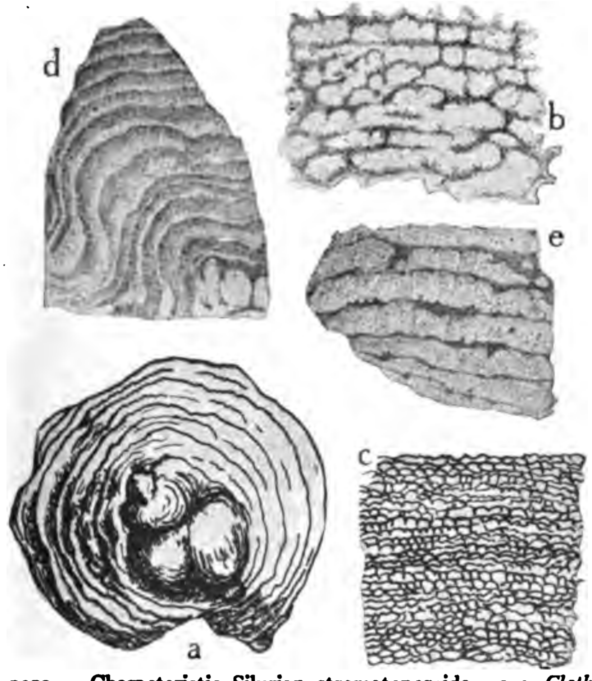


FIG. 1210. — Characteristic Silurian stromatoporoids. *a–c, Clathrodictyon vesiculosum:* (*a*) under or epithecal side; *b*, section of the same enlarged about 50 times; *c*, section enlarged about 10 times, Clinton-Niagaran; *d–e, Stromatopora antiqua*, Niagaran: *d*, section; *e*, part of section enlarged 1½ diameters. (I. F.)

ing practically its first appearance with many species, while the chain coral, *Halysites* (Fig. 1161), is most characteristic, as is also the tube coral, *Syringopora* (Fig. 1206). Many remarkable single corals are also known, especially from Europe, including the curious *Omphyma* (Fig. 1208) with its root-like excrescences, and the remarkable quadrangular *Goniophyllum* with four-parted operculum (Fig. 1209). **Stromatoporas** are also abundant and of

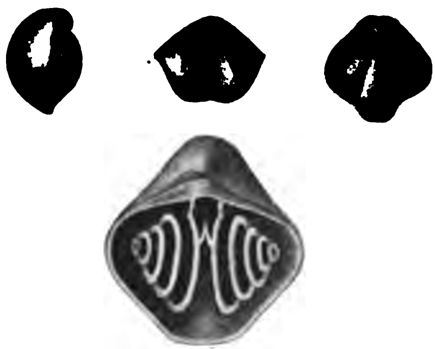


FIG. 1211. — *Hyattidina congesta*. Characteristic of the Atlantic or Clinton type of Silurian fauna. (After Hall and Clarke.)

characteristic types (*Clathrodictyon*, etc., Fig. 1210) quite unlike any of the hydrocorallines found in the Ordovician. The **Bryozoa** are still abundant, but mostly derivatives from Ordovician types. The **brachiopod** fauna, on the whole, is very characteristic. The thin Rafinesquinas are replaced by *Schuchertella* (Fig. 1170 *e*) and *Stropheodonta* (Fig. 1178), the latter with notched hinge line. The Orthis group is largely confined to the short-hinged types

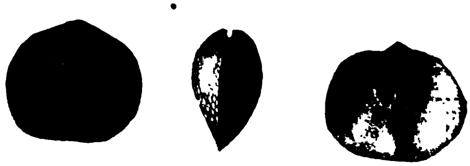


FIG. 1212 *a*. — *Rhipidomella hybrida*, Niagaran (Rochester shale, etc.), dorsal and lateral views and interior of pedicle valve.

FIG. 1212 *b*. — *Whitfieldella nitida*, Lower Silurian (Niagaran). (K.)

of more or less circular section (*Dalmanella elegantula*, Fig. 1159; *Rhipidomella*, Fig. 1212 *a*). The smooth-shelled biconvex *Whitfieldellas* abound (Fig. 1212 *b*) and Spirifers appear with startling abruptness, being practically unknown in the older rocks. Most of them are still small forms (Fig. 1170 *a*, 1177) but a few large ones occur (*S. niagarensis*, Fig. 1158; *S. radiatus*, Fig. 1213 *b*). Pentameroid shells, readily recognized by the internal structure, are also prominent, including both smooth-shelled biconvex types

(*Pentamerus*, Fig. 1153, p. 318) and plicated types with strongly arched pedicle valve (*Conchidium*, Fig. 1213 *c*). The plicated rhynchonelloids are represented

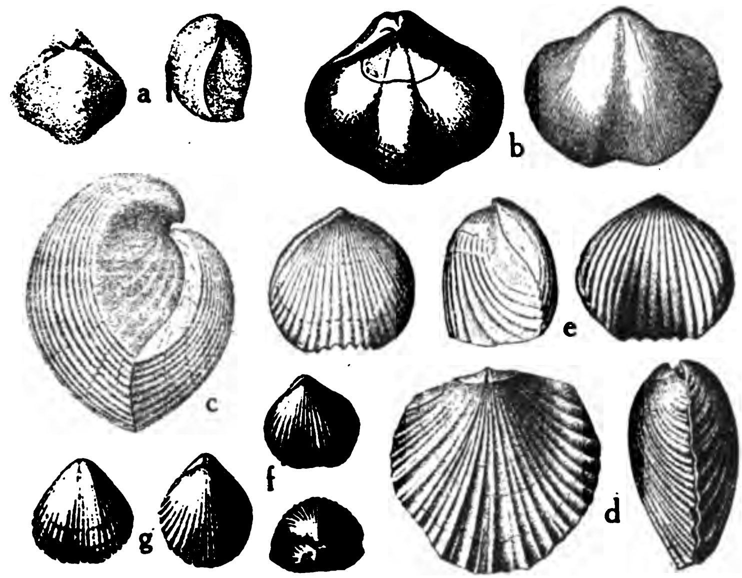


FIG. 1213 *a–g*. Characteristic Niagaran brachiopods of North America; (*a*), *Meristina maria*; (*b*), *Spirifer radiatus*; (*c*), *Pentamerus* (*Conchidium*) *nettelrothi*; (*d*) *Stricklandinia castellana*; (*e*), *Uncinulus stricklandi*; (*f*), *Anastrophia internascens*; (*g*), *Homœospira evax*. (I. F.)

by *Camarotœchia* (Fig. 1214), *Rhynchotreta* (Fig. 1160 *a*), and others. Finally, there are peculiar specialized brachiopods which developed a remarkable

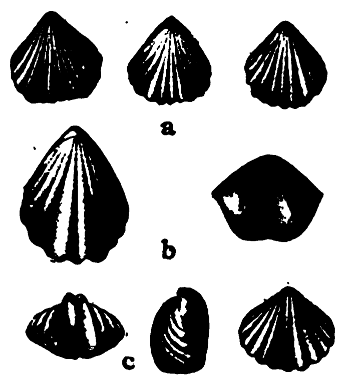


FIG. 1214. — Silurian (Niagaran) Rhynchonelloids. *a*, *Camarotœchia indianensis*; *b*, *C. acinus*; *c*, *C. whitii*. (I. F.)

internal platform (*Trimerella*, Fig. 1215, etc.), and which appear to represent the products of peculiar conditions of environment.

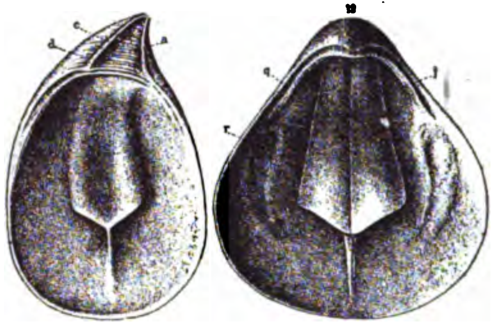


FIG. 1215. — *Trimerella ohioensis*. Interiors of pedicle and brachial valves (I. F.)

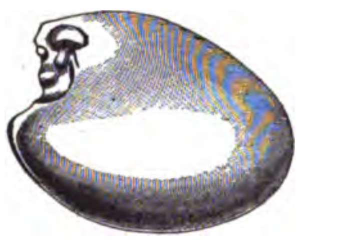


FIG. 1216. — *Megalomus canadensis*, a characteristic pelecypod of the Guelph formation. (Internal mold, ×½.) (I. F.)

FIG. 1217. — *Cardiola cornucopiæ*, a European Upper Silurian (Ludlow) pelecypod. (Kayser.)

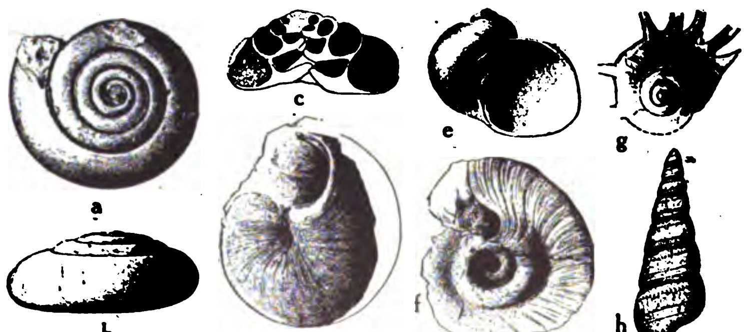


FIG. 1218. — Characteristic Silurian (Niagaran) gastropods of North America. *a-d*, *Pycnomphalus solarioides*, Guelph; *a*, *b*, internal mold; *c*, section of shell; *d*, under (umbilical) view of shell; *e*, *Strophostylus cyclostomus*; *f*, *Euomphalopterus valerius*, Guelph, umbilical view; *g*, *E. elora*, top view (Guelph); *h*, *Acanthonema newberryi* (enlarged), upper Monroan. (I. F.)

The **pelecypods** are less distinctive, though a large form, *Megalomus* (Fig. 1216), is very characteristic of some beds, while *Cardiola* (Fig. 1217) is typical of the European Silurian. **Gastropods** are represented by many types both low and high spired, and they are often strongly ornamented, especially

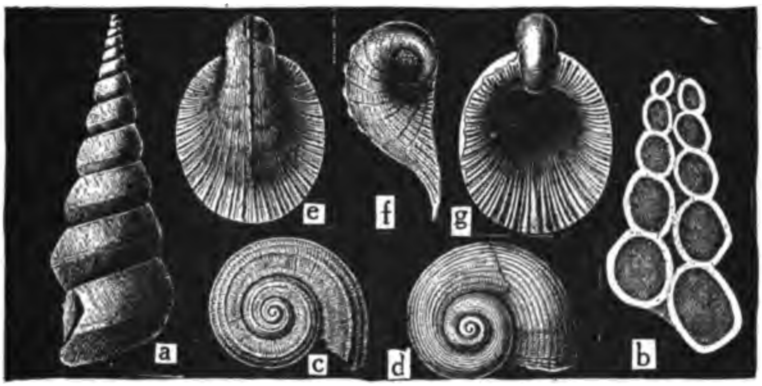


FIG. 1219. — Characteristic Niagaran (Guelph) gastropods. *a–b*, *Cœlidium macrospira*, shell and section; *c*, *Poleumita crenulata*; *d*, *P. scamnata*; *e-g*, *Trematonotus alphæus*, about ½ natural size. (Clarke and Ruedemann.)

in the Upper Silurian (Figs. 1218–1220). *Conularia* and *Tentaculites* (Fig. 1175, p. 328) are the chief representatives of the **Conularidæ**. The most characteristic **cephalopods** are the ringed orthoceran types (*Dawsonoceras*, Fig. 1221 *b*) and the curved cyrtoceran forms, often with contracted aperture (*Phragmoceras*, Fig. 1223 *d*; *Gomphoceras*, Fig. 1223 *b*, *c*, etc.). Finally there are many forms

FIG. 1220. — *Hercynella*, a pulmonate gastropod from the Upper Silurian and Lower Devonian (*H. bohemica*, Étage F. Bohemia). (Zittel.)

with spiral coils resembling large gastropod shells (*Trochoceras*, etc., Figs. 1221 *d*, *e*, 1223 *a*), not known from older horizons. **Trilobites** are still abundant, the leading forms being *Dalmanites* (Fig. 1224), *Calymmene* (Fig. 1225), *Illænus*, etc. (Fig. 1226 *a*, *b*), *Bronteus* (Fig. 1227), *Lichas* (Fig. 1228), and others. Other crustaceans, especially **ostracods**, abound (Fig 1229). **Eurypterids** are at their height of development in Silurian strata and many genera occur

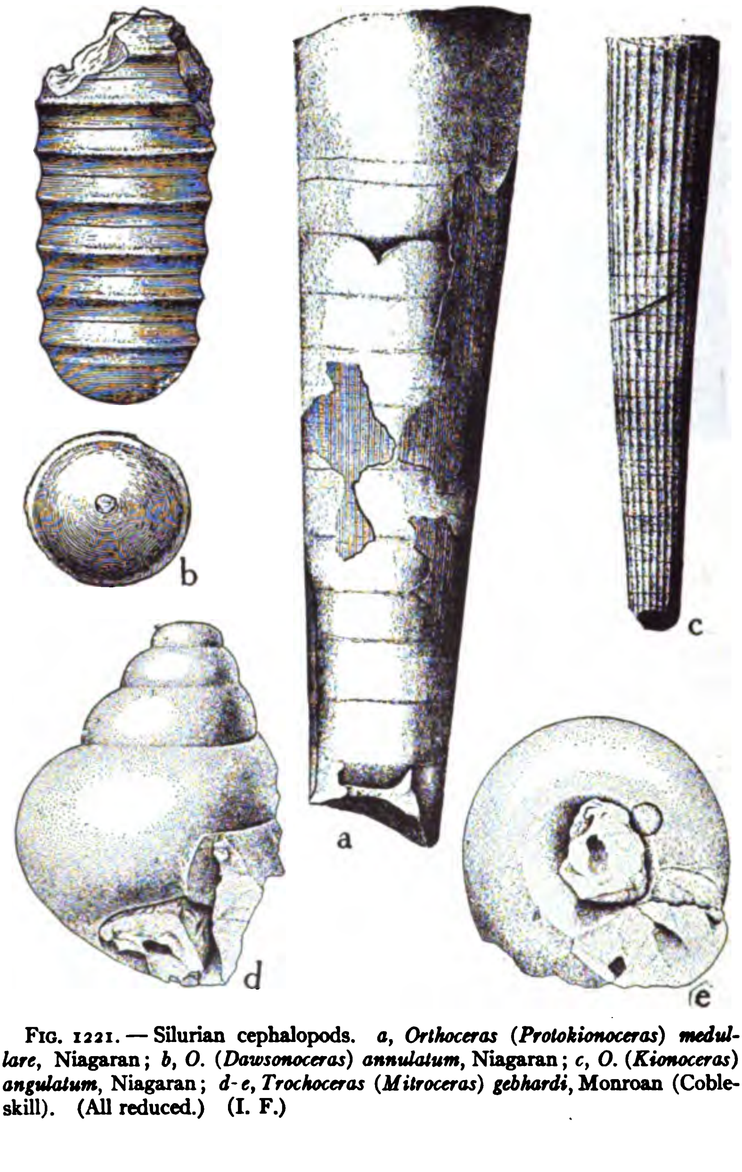


FIG. 1221. — Silurian cephalopods. *a*, ***Orthoceras*** **(*Protokionoceras*)** ***medullare***, Niagaran; *b*, *O.* (***Dawsonoceras***) ***annulatum***, Niagaran; *c*, *O.* (***Kionoceras***) ***angulatum***, Niagaran; *d-e*, ***Trochoceras*** **(*Mitroceras*)** ***gebhardi***, Monroan (Cobleskill). (All reduced.) (I. F.)

FIG. 1222. — *Cyrtoceras (Mælonoceras) arcticameratum.* A characteristic cyrtoceran shell of the Lower Silurian (Guelph). (Clarke and Ruedemann.)

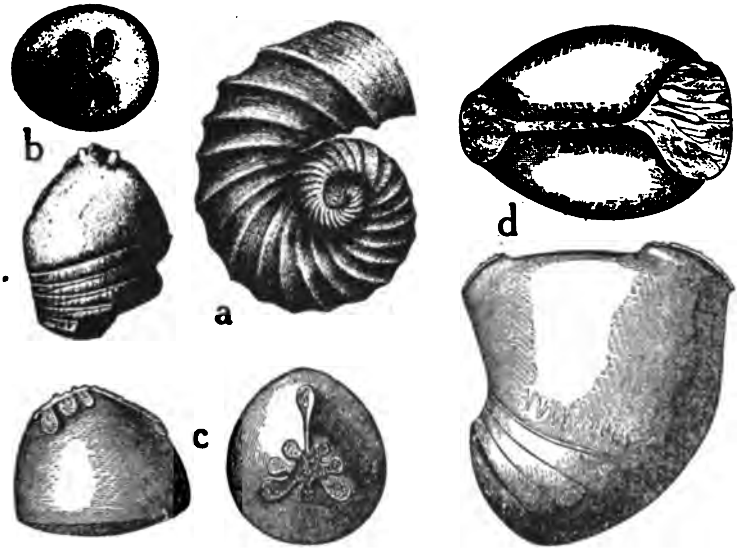


FIG. 1223. — Characteristic Silurian (Niagaran) cephalopods of North America. *a, Trochoceras (Sphyradoceras) desplainense*, about one half natural size; *b, Gomphoceras (Hexameroceras) herzeri* (× ½), top showing contracted aperture and side views with several chambers; *c, Gomphoceras (Septameroceras) septoris*, side and top view of living chamber, showing contracted aperture; *d, Phragmoceras nestor*, top view showing contracted aperture, and side view showing curvature and several chambers. (I. F.)

FIG. 1224. — *Dalmanites caudata.* Lower Silurian. (Wenlock.) Europe. (Kayser.)

FIG. 1225. — *Calymmene niagarense.* Top and side views. (Niagaran.)

FIG. 1226 *a.* — *Illænus ioxus.* Cephalon and pygidium (Niagaran). (I. F.)

FIG. 1226 *b.* — *Sphærexochus romingeri.* Cephalon, top and side views, and pygidium (Niagaran). (I. F.)

there. These and certain crustacean forms are regarded as inhabitants of the rivers of the period (Fig. 1230). The oldest **scorpions** are known from the Upper Silurian deposits (Fig. 1231), and it is possible that scorpions developed from eurypterid-like ancestors (river types) during the period of

FIG. 1227. — *Bronteus planus*. Lower Silurian. (Wenlock.) Europe. (Kayser.)

FIG. 1228. — *Lichas boltoni*. Niagaran (Rochester shale); much reduced. (I. F.)

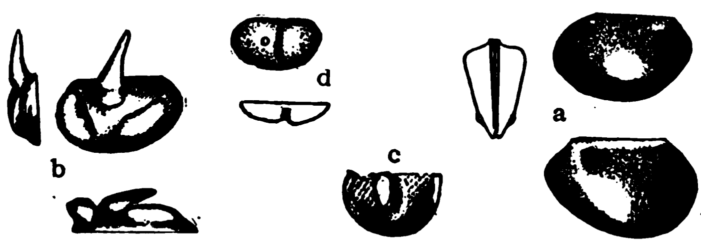


FIG. 1229. — Characteristic Silurian ostracods. *a*, *Leperditia angulifera*, right, left, and anterior views (Lower Monroan); *b*, *Æchmina abnormis*, right valve (×10) (Niagaran); *c*, *Beyrichia granulosa* (×7) (Niagaran); *d*, *Entomis waldronensis*, lateral and dorsal views of left valve (×1) (Waldron shales of the Niagaran). (I. F.)

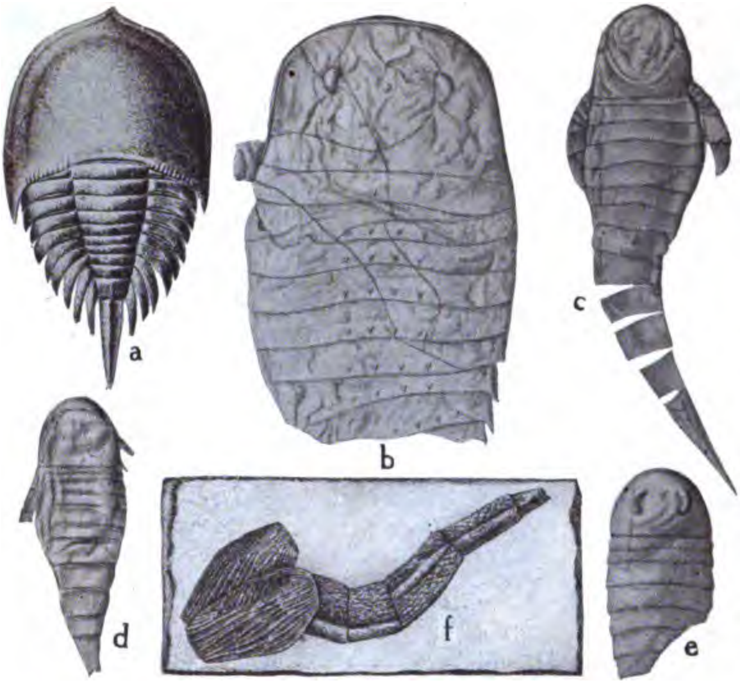


FIG. 1230. — Characteristic river and estuarine Merostomes (*a-e*) and a crustacean (*f*) of the North American Silurian. *a*, *Pseudoniscus roosevelti*, a synxiphosuran ($\times 2$), Pittsford shale and Bertie waterlime; *b*, *Eurypterus pittsfordense*, anterior portion ($\times \frac{4}{9}$), Pittsford shale; *c*, *Hughmilleria socialis* ($\times \frac{2}{3}$), Pittsford shale; *d*, *Hughmilleria shawangunk* (young), black shales in Shawangunk conglomerate; *e*, *Eurypterus maria* (young, much enlarged), black shale layers in Shawangunk conglomerate; *f*, *Emmelezoe decora*, a phyllocarid ($\times 2$), Pittsford shale. (See also Figs. 934 and 1169.)

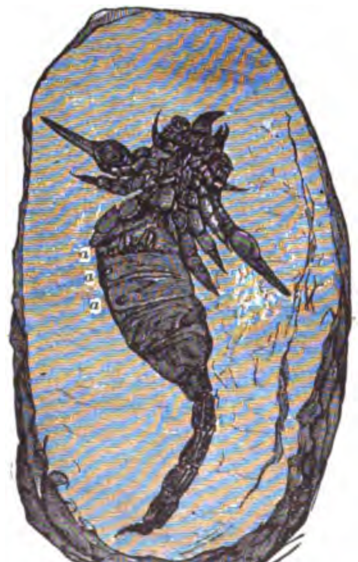


FIG. 1231. — *Palæophonus caledonicus* ($\times 2$), a fossil scorpion. Upper Silurian (upper Ludlow), Lanarkshire, Scotland. (From a drawing by Dr. Peach.)

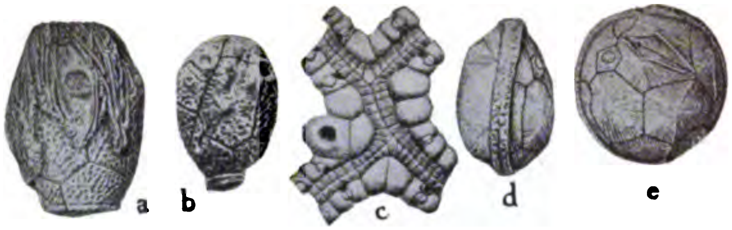


FIG. 1232. — Silurian cystoids (Niagaran and Monroan). *a*, *Collocystites canadensis*, Rochester shale; *b*, *c*, *Jækelocystis hartleyi*, with enlargements of oral end, Manlius; *d*, *e*, *Pseudocrinites gordoni*, Manlius.

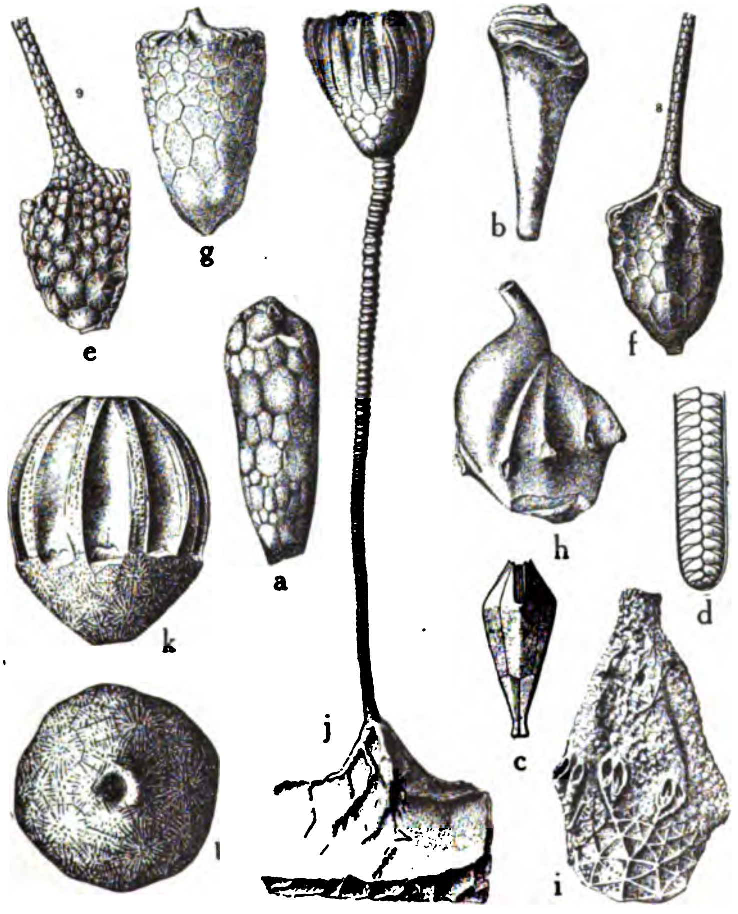


FIG. 1233. — North American Silurian (Niagaran) cystoids (*a*-*b*), blastoids (*c*-*d*), and crinoids (*e*-*l*). *a*, *Holocystites alternatus*; *b*, *Gomphocystites glans*, internal mold; *c*, *d*, *Troostocrinus reinwardti* (×1⅓), with ambulacrum much enlarged; *e*, *f*, *Periechocrinus* (*Saccocrinus*) *ornatus*; *g*, *P. tennesseensis*; *h*, *i*, *Siphonocrinus nobilis*, internal mold and exterior; *j*, *Eucalyptocrinus crassus*, about half natural size; *k*, *l*, *Eucalyptocrinus elrodi*, lateral and basal views.

mid-Silurian widespread land conditions which placed a premium upon ability to breathe air. **Insects** probably existed but are little known. **Cystoids** still abound (*Caryocrinus*, Fig. 1157; *Callocystites*, Fig. 1232), and **crinoids** have

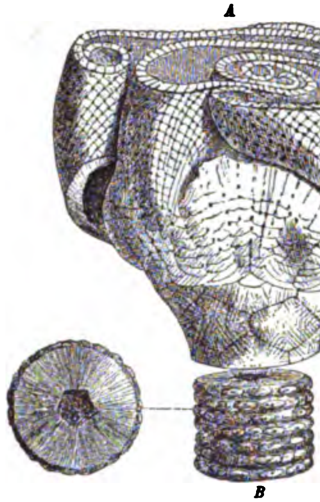


FIG. 1234. — A crinoid (*Crotalocrinus pulcher*) from the Silurian of Gotland. *A*, crown with folded arms; *B*, portion of stem. (After Angelin.)

become more abundant (*Ichthyocrinus*, *Eucalyptocrinus*, etc., Fig. 1233). **Blastoids**, too, are present (*Troostocrinus*, Fig. 1233 *c*, *d*). Other echinoderms are rare. **Fish** (ostracoderms) abounded in the rivers, and are found especially

FIG. 1235. — *Sphærocodium gotlandicum*, a typical calcareous alga of the Silurian. Natural size, Gotland. (After Munthe.)

in Upper Silurian deposits. They are closely related to Devonian types. Higher **vertebrates** and **land plants** are still unknown, though the latter probably existed. **Marine plants**, however, existed, especially the lime-secreting algæ, *Sphærocodium* (Figs. 1235, 1236), *Girvanella*, etc. They abound in the rocks of Gotland and other parts of Sweden (Fig. 1237).

FIG. 1236.—*Sphærocodium gotlandicum*, a section showing characteristic micro-structure, enlarged forty times. (After Munthe.)

FIG. 1237.—The late Professor A. Rothpletz of Munich examining for *Girvanella* a fossiliferous slab in a quarry in Silurian limestones in Gotland, Sweden. He is standing on the top bed of the Lower Silurian (Lower Gotlandian). See Fig. 1198 *b*. (Photo by the author, 1910.)

CHAPTER XXXV

THE DEVONIAN OR DEVONIC SYSTEM

BEFORE the discovery of the marine formations on which this system was founded, the strata which in England were found to separate the Coal-measures and Carboniferous Limestone series from the old graywackes were familiarly known as the Old Red Sandstone, the lower of the two great red sandstone series which had been widely traced in the British Isles. The Old Red Sandstone is most typically developed in Scotland, where the labors of Hugh Miller have made them widely known. Miller (portrait, Fig. 1238) was a self-educated geologist, and master of a good literary style, albeit a stone-mason by profession. Born in 1802 in a small straw-thatched cottage (Fig. 1239) in the fishing-town of Cromarty, on the northeast coast of Scotland, his early life was spent among humble surroundings but within easy reach of the wonderful sections of that picturesque portion of the Scottish coast. As boy and man, apprentice, journeyman, and master-mason, he searched out the fossil treasures of the Old Red Sandstone and the other formations of his native land, and in his mature

FIG. 1238. — HUGH MILLER.

FIG. 1239. — The birthplace of Hugh Miller in Cromarty, Scotland. (Photo by author.)

years made them and the characters of the rocks themselves known to the scientific world by his facile pen.[1] The Old Red Sandstone is a purely continental formation, formerly thought to have been deposited in great fresh-water lakes, but now recognized to be of flood-plain and playa origin, the result of torrential, and in part perhaps of eolian, deposition. It was not regarded as representing a distinct system in the geological succession. When, however, it was found that the rocks beneath the Carboniferous beds of Devon and Cornwall, which Sedgwick and Murchison at first referred to the Cambro-Silurian, contained distinctive fossils which placed these rocks between the Silurian and the Carboniferous Limestone series, it became apparent that a new system had been discovered, and that it held the same position in the geological succession as that occupied by the Old Red Sandstone farther north. To this new system the name Devonian was applied by Sedgwick and Murchison in 1837, the exposures in Devonshire becoming the type section (Figs. 1240, 1241). As is the case with most of the older rocks of England, the Devonian strata of Devonshire are much disturbed, and the series is incomplete; and because of the disturbance and the partial metamorphism of the strata, the fossils are often poorly preserved. A far better section

FIG. 1240. — Coast scene at Torquay, South Devonshire, England, showing cliffs of Devonian rocks in the type region.

[1] Among his literary works, *The Old Red Sandstone, or New Walks in an Old Field* easily stands first, and with this the student should familiarize himself.

of the Devonian rocks is found in western Germany and the adjoining districts of Belgium. The rocks into which the Rhine has cut its beautiful gorge (Fig. 601, p. 703, Pt. I) belong to this system,

FIG. 1241. — Upper Devonian strata in the type region, in southwestern England. (Padstow, Cornwall.) These strata are alternating limestones and shales. (Geol. Survey, England, from Lake and Rastall.)

but less disturbed and more fossiliferous Devonian rocks, chiefly limestones, which commonly exhibit coral-reef structure, are found in the famous Eifel district (Fig. 1242). This and the Bohemian

FIG. 1242. — Devonian coral reefs and limestones now forming high cliff above Gerolstein in the Eifel, Germany.

region (Fig. 1243), form the two best-known and, in many respects, most characteristic districts in which the Devonian rocks of Europe are preserved.

Devonian rocks are widespread over Russia, extending to the Arctic regions. They present both the Old Red Sandstone and the marine type. They are found in the Ural Mountains and are widespread in central Asia. They also occur in South America.

Once more, however, North America furnishes the most complete record of the Devonian formations, because here the rocks are not

Fig. 1243. — Collecting Lower Devonian fossils in a limestone quarry at Konjepruss, Bohemia; Mareck, the field assistant of Joachim Barrande. (Photo by author.)

only preserved over wide areas, but are, for the most part, little disturbed. Again the state of New York has given us the type sections for the North American Devonian and, therefore, in a measure, the type sections for the Devonian of the world. Next in importance to those of New York are the exposures found in Michigan, which extend into Wisconsin and Iowa on the one hand, and into Ontario, Ohio, and Indiana on the other. The Appalachians include Devonian rocks in their folds in Pennsylvania, Maryland, and Virginia, and the Rocky Mountains and the northwest Canadian region also present Devonian strata, often in considerable thickness.

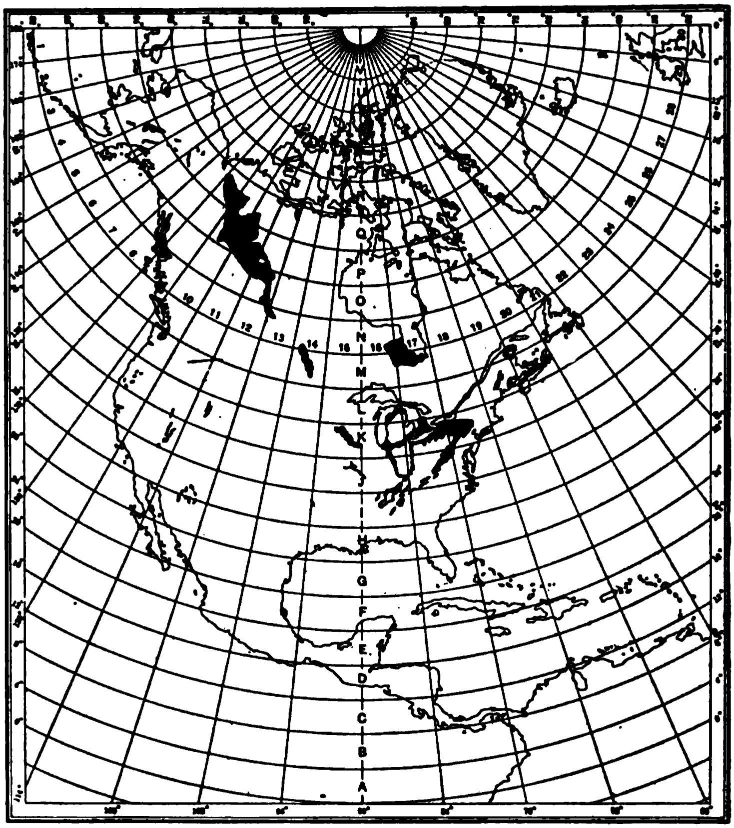


FIG. 1244. — Map showing the outcrops of the Devonian rocks in North America. (After Bailey Willis.)

THE DEVONIAN FORMATIONS OF NORTH AMERICA

The Devonian period, like the Silurian, opened with restricted seas in both America and the Old World, but the areas of continuous deposition are more extensive than was the case at the opening of the Silurian.

Classification and Subdivisions

The Devonian formations of North America, as we have seen, are typically developed in the state of New York, more than one half of its area being covered by these rocks. The succession is very complete and must serve as the standard for comparison for other regions. The following major divisions are recognized:

Upper Devonian	Chautauquan division	Chemung-Catskill group.
	Senecan division	Portage group. Naples, Ithaca, and Oneonta beds. Genesee-Tully group.
Middle Devonian	Erian division	Hamilton group.
	Ulsterian division	Marcellus-Onondaga group. Schoharie-Esopus group.
Lower Devonian	Oriskanian division	Oriskany-Port Ewen group.
	Helderbergian division	Helderberg formations.

Characteristic Sections

Helderberg-Catskill Section. — The most complete and continuous section of the Devonian strata is found in the Helderberg and Catskill Mountains of eastern New York. The series here is com-

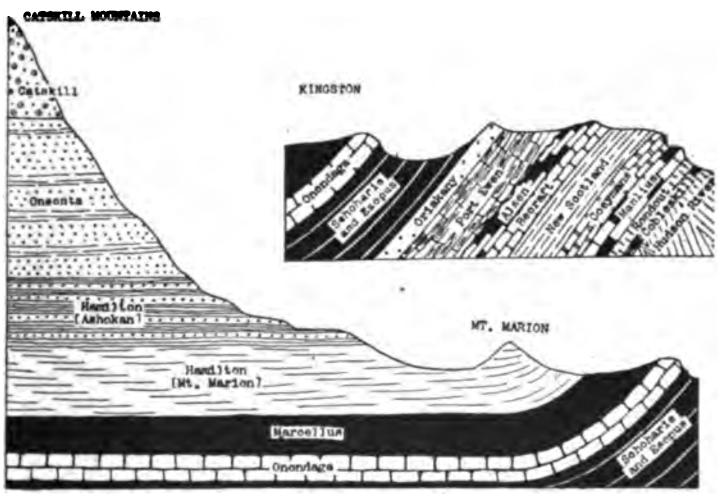


FIG. 1245. — Section from the Hudson River near Rondout, New York, to the top of the Catskill Mountains, showing the unconformable superposition of the Upper Silurian upon the Ordovician, and the conformable succession of the Devonian formations from the Coeymans to the Catskill. The thickness of the higher formations (Oneonta and Catskill) is not fully represented. (Original.)

plicated by one or more overthrusts and many faults, and in some sections the strata have been strongly folded. For greater simplicity the faults and thrusts will be omitted so that the section as here given is not wholly true to the actual (Fig. 1245).

At Kingston, as we have seen, the Cobleskill limestone rests unconformably upon the Ordovician sandstone and is followed

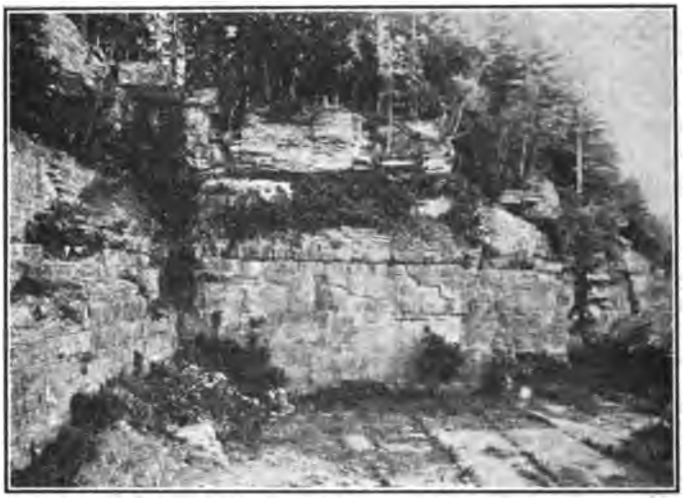


FIG. 1246. — Section of Upper Silurian and Lower Devonian strata exposed in Becker Quarry, Schoharie, New York. The floor and lower face of the quarry expose the Manlius limestone; the brush-covered retreating portion is formed by the transition beds; the upper cliff is formed of the Coeymans limestone. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

by the Rondout waterlime and the Manlius limestone which form the top of the Silurian. Upon this, with perfect conformity, follows the first of the Helderberg beds, the *Coeymans limestone.*

FIG. 1247. — *Gypidula coeymanensis.* Coeymans. The lower figure shows the interior of the pedicle valve with the spondylium. (I. F.)

This is the characteristic relationship throughout the Helderberg escarpment (Fig. 1246). At Kingston the Coeymans is about 50 feet thick and contains many characteristic fossils, among which

Gypidula coeymanensis (Fig. 1247) may be noted. Then follow about 75 or 100 feet of more shaly limestones in which, gradually, new species of fossils appear, while *G. coeymanensis* is absent.

FIG. 1248. — *Spirifer macropleura.* New Scotland. Reduced. (I. F.)

Most typical of this second division, the *New Scotland*, is *Spirifer macropleura* (Fig. 1248), but there are many others. The third division is a very pure shell limestone, the *Becraft*, much valued for the making of Portland cement. It is named from Mt. Becraft

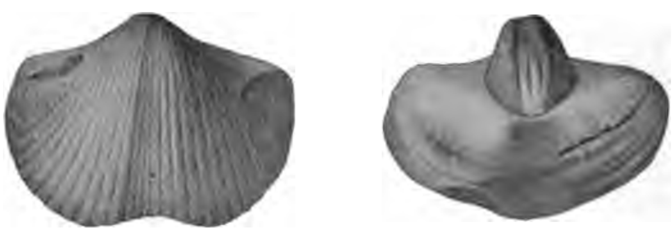
FIG. 1249. — Cliff of Lower Devonian Becraft limestone on the slopes of Dan's Hill, Schoharie. The cave and the pillar of the overhanging ledge are formed by the upper New Scotland transition beds. (See Fig. 1264 *b*.) (Courtesy N. Y. State Museum, John M. Clarke, Director.)

near Hudson, N. Y. (Fig. 1249). Its thickness is about 40 feet, and it is characterized by many species of fossils which appear for the first time, most typical among them being *Gypidula pseudogaleata* (Fig. 1250 *a*) and *Spirifer concinnus* (Fig. 1250 *b*). A fourth division, the *Alsen*, is of variable thickness and differs from the preceding mainly in the presence of chert bands; *G. pseudogaleata* is absent, but *Spirifer concinnus* is common. The top of this rock series is characterized by an erosion surface indicating a

FIG. 1250 *a*. — *Gypidula pseudogaleata*. Becraft. (I. F.)

FIG. 1250 *b*.—*Spirifer concinnus*. Becraft and Alsen. (I. F.)

break in the section. Resting disconformably upon this surface is an impure shaly limestone with lenses of more calcareous matter, the *Port Ewen*, 100 or more feet thick in this region, but absent farther north. Besides many fragments of fossils, evidently worn from the underlying rocks, this formation contains new species,



a *b*

FIG. 1251 *a*. — *Spirifer arenosus*. Oriskany. *a*, exterior of pedicle valve, *b*, interior mold of same. Reduced. (I. F.)

many of them characteristic of the Oriskany formation of which it is a part and into which it grades. The *Oriskany* is largely a sandstone, sometimes finely conglomeratic but with calcareous matter as well. It is characterized by *Spirifer arenosus* (Fig. 1251 *a*), *S. murchisoni* (Fig. 1251 *b*), *Rensselæria ovoides* (Fig. 1252 *a*), *Hipparionyx proximus* (Fig. 1252 *b*), etc. It is about 60 feet thick. Then follow dark silicious shales, several hundred feet thick, weathering readily and producing valleys. This is the *Esopus-*

FIG. 1251 *b*. — *Spirifer murchisoni*. Oriskany. Pedicle and side views and internal mold of pedicle valve. Reduced. (I. F.)

Schoharie series, which becomes more calcareous upward and grades into the *Onondaga limestone* (Fig. 1253), a massive cherty rock 50 feet or more in thickness and carrying corals (*Favosites, Zaphrentis*,

FIG. 1252 *a*. — *Rensselaeria ovoides*. Oriskany. Reduced. (I. F.)

Fig. 1254) and other fossils (Figs. 1255–1257). Another black shale, the *Marcellus*, several hundred feet thick, with few and small fossils and very bituminous, succeeds this limestone and also forms valleys, and it passes upward into more sandy shales

FIG. 1252 *b.* — *Hipparionyx proximus.* Oriskany. Side view of convex (brachial) valve and impression of flat (pedicle) valve, showing the muscle scars. (I. F.)

FIG. 1253. — Onondaga limestone, at the northern edge of the Allegheny plateau. Deep solution fissures are formed along the joint cracks. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

and sandstones with marine fossils (*Spirifer mucronatus*, Fig. 1258 *a*; *Tropidoleptus carinatus*, Fig. 1258 *b*, etc. (Figs. 1258 *c*, *d*))

FIG. 1254. — *Zaphrentis prolifica*. Onondaga.

FIG. 1255. — *Syringopora perelegans*. Onondaga. (After Rominger.)

about 500 feet thick which form the lower *Hamilton* or Mt. Marion beds. These are in turn succeeded by the upper Hamilton or Ashokan beds, 600 feet thick, which furnish the best of the Hudson

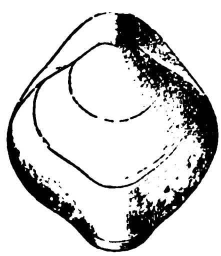


FIG. 1256 *a*. — *Meristella nasuta*; Schoharie-Onondaga. (Hall and Clarke.)

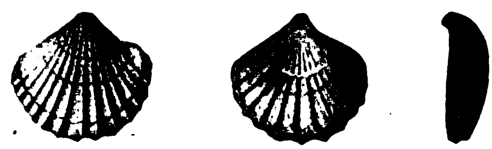


FIG. 1256 *b*. — *Leptocœlia flabellites*. Oriskany and Onondaga, of world-wide distribution. (I. F.)

River bluestone or flagstones (Fig. 1259) and are non-marine delta deposits. See Figs. 486 and 487, pp. 578, 579, Pt. I. The next series represents the *Portage* group, and consists of bluestone and red and gray or greenish shales carrying plant remains at intervals (*Oneonta* series, Figs. 1260, 1261). These are about 3000 feet thick and are capped by the *Catskill* sandstones (Fig. 1262), chiefly

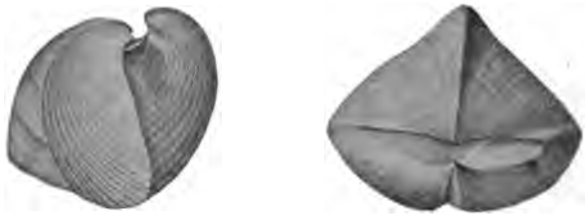


FIG. 1257. — *Spirifer acuminatus.* Onondaga. (I. F.)

FIG. 1258 *a.* — *Spirifer mucronatus.* Hamilton shales. (I. F.)

FIG. 1258 *b.* — *Tropidoleptus carinatus;* three views. Hamilton shales. (I. F.)

FIG. 1258 *c.* — *Pterinea* (*Cornellites*) *flabellum.* Hamilton shales. (I. F.)

FIG. 1258 *d.* — *Phacops rana.* Hamilton. (I. F.)

red, and some white beds which extend to the top of the Catskill Mountains, a thickness of about 1000 feet remaining after much erosion. In Pennsylvania these beds are 5000 feet thick. They

FIG. 1259. — Stewart flagstone quarry in upper Hamilton formation north of Rensselaerville, N. Y. The flagstones are obtained from the massive layers in the bottom of the quarry (4½ to 6 ft.) above which lie shales with Hamilton fossils, capped by glacial material. (Photo by C. S. Prosser; courtesy N. Y. State Museum, John M. Clarke, Director.)

FIG. 1260. — The Rocks, Conesville, New York. An exposure of Oneonta sandstone (Upper Devonian). (Courtesy N. Y. State Museum, John M. Clarke, Director.)

include at some horizons fresh or brackish water clams (Fig. 1263).

Analysis of the Section. — The Lower Devonian beds represent continuous deposition upon the Upper Silurian and comprise a series of limestones primarily of organic matter, chiefly shells, with

FIG. 1261. — Oneonta sandstones and shales (red and green) at Manorkill Falls, New York, above the bridge. (Courtesy New York State Museum, John M. Clarke, Director.)

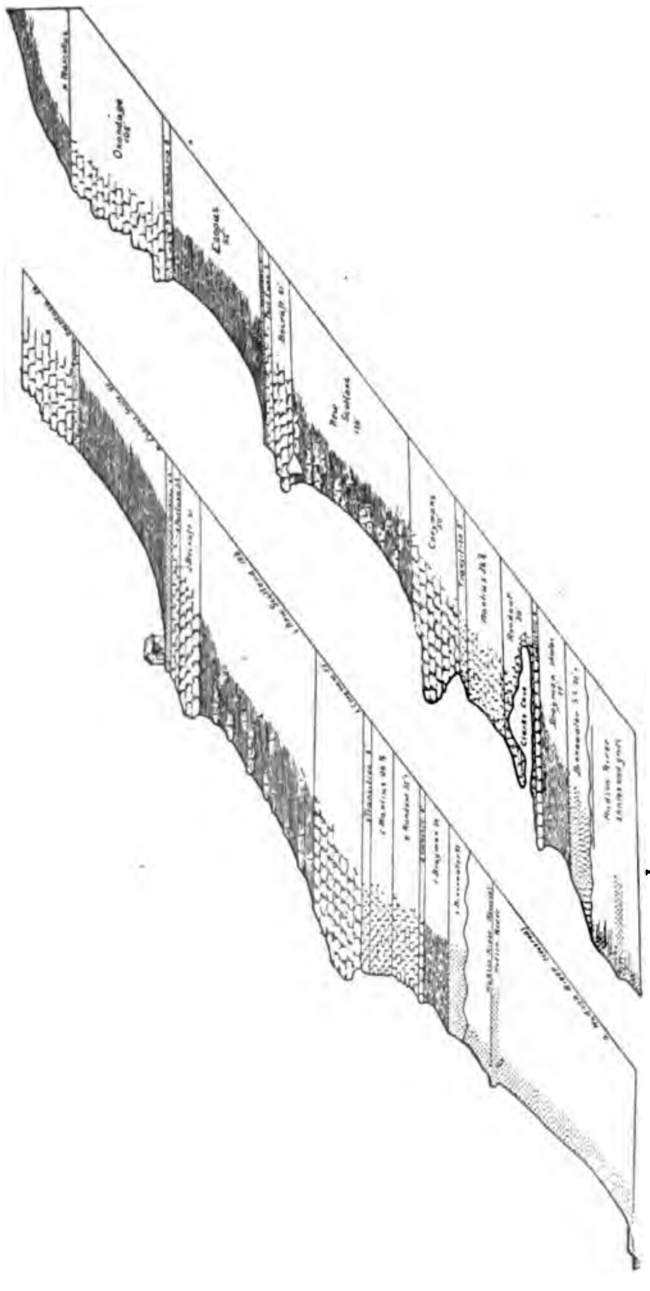
a minimum of terrigenous material. The series is terminated by an erosion plane which marks a withdrawal of the sea. This erosion plane is found everywhere in the Appalachian trough except at its northern end (Gaspé), where a vastly greater thickness of limestones represents the Helderberg series (1200 feet). Above the erosion plane follows a detrital lime-rock (Port Ewen) apparently formed from material eroded from the Helderberg series, and recemented in the depressed areas into which it was

FIG. 1262. — Catskill formation, Kaaterskill Falls, N. Y. (Courtesy New York State Museum, John M. Clarke, Director.)

washed. It is covered by the Oriskany sandstone. In parts of Pennsylvania the Port Ewen beds rest upon the Coeymans lime-

FIG. 1263. — *Amnigenia catskillensis.* Oneonta and Catskill. (I. F.)

stone, the higher Helderberg beds being eroded. In Maryland the Oriskany sandstone rests on Becraft limestone. In the northern



FIGS. 1264 *a*, *b*.—*a*, Section of West Hill, Schoharie, New York. (See photograph, Fig. 17, p. 32, Pt. I.) *b*, Section of Dan's Hill, Schoharie, New York. These sections show the late Ordovician, Upper Silurian, and Lower and Middle Devonian formations. (From Grabau, *Geology of Schoharie*, N. Y. State Museum Report.)

end of the trough (Gaspé) the Oriskanian series consists almost entirely of limestones, 800 feet thick. The unfossiliferous Esopus-Schoharie muds are followed by the Onondaga coral-limestone, and

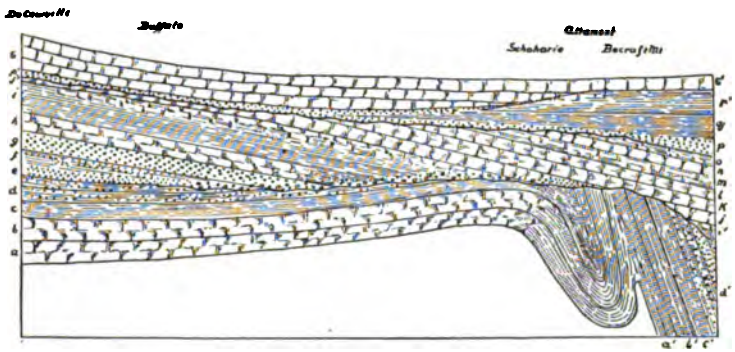


FIG. 1265. — Diagram of the relationship of the Ordovician, Silurian, and early Devonian strata of New York. *a*, Beekmantown; *a'*, Deepkill shales; *b*, Black River-Trenton; *b'*, Normanskill-Canajoharie shale; *c*, Utica shale; *d*, *d'*, Lorraine; *e*, Oswego sandstone; *e'*, Shawangunk conglomerate; *f*, Queenston shales; *g*, Medina sandstones; *h*, Clinton-Niagara; *i*, Salina-Bertie; *i'*, High Falls-Rosendale; *j*, Cobleskill-Rondout; *k*, Manlius; *l*, Coeymans; *m*, New Scotland; *n*, Becraft; *o*, Alsen; *p*, Port Ewen-Oriskany; *p'*, Decewville; *q*, Esopus; *r*, Schoharie grit; *r'*, Schoharie shales; *s*, *s'*, Onondaga limestone.

this is succeeded by black muds which grade upward into sandy shales. Above the lower Hamilton the series is wholly non-marine, beginning with bluestones and ending with red beds, indicating a progressive change toward aridity.

FIG. 1266. — Section (partly on Lake Erie) in western New York, from the head of the Niagara River to the hills of southern New York, showing the succession of the Devonian strata. (Original.)

The sections of the Helderberg escarpment farther to the northwest at Schoharie (Fig. 1264) are somewhat simpler and less complete, and are here given for comparison (Fig. 1265).

Lake Erie Section. — In the western part of the state of New York the strata have a very gentle southerly dip (Fig. 1266).

At Buffalo the Onondaga limestone rests disconformably upon the Cobleskill (Fig. 1168, p. 324), all the intervening beds being absent,

FIG. 1267. — Outcrop of Marcellus shale, showing the numerous joint planes and their effect on the rapidity of weathering. The exposure is on a small brook which carries away the talus as it is formed. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

except a layer of sand grains which represents the Oriskany. The Onondaga is nearly 200 feet thick and often shows coral reef

FIG. 1268. — Upper Marcellus shale, shore of Lake Erie. (I. P. Bishop, photo.)

structure. The Marcellus is a black bituminous shale, much thinner than in the east (Figs. 1267, 1268), and grades upward into more calcareous shales, the Hamilton, very rich in fossils and with several thin limestone beds (Fig. 1269). It is terminated by a layer of iron pyrites with fossils, which in central New York be-

FIG. 1269. — Section of Devonian strata, Eighteen Mile Creek, N. Y. Middle Devonian (Hamilton) beds in lower half (part of upper Ludlow shale, Morse Creek limestone, Windom shales), covered by projecting *Styliolina* (Genundewa) limestone and the black lower Portage shales of the Upper Devonian. (I. P. Bishop, photo.)

FIG. 1270. — Projecting ledge of Tully limestone with upper Hamilton (Moscow) shale beneath. Tinker's Falls near Tully, N. Y. (Charles H. Shamel, photo.)

comes the Tully limestone, 25 feet in thickness (Figs. 1270, 1271). Among its characteristic fossils *Hypothyris cuboides* (Fig. 1279 *a*) may be noted. The Genesee shale is also thin in western New

Fig. 1271. — Quarry in Tully limestone, Tully, N. Y. (Charles H. Shamel, photo.)

York (Fig. 1269), but 75 feet or more in thickness in central New York (Fig. 1272), where it is a black bituminous shale with few fossils. Farther east its place is partly taken by the *Sherburne*

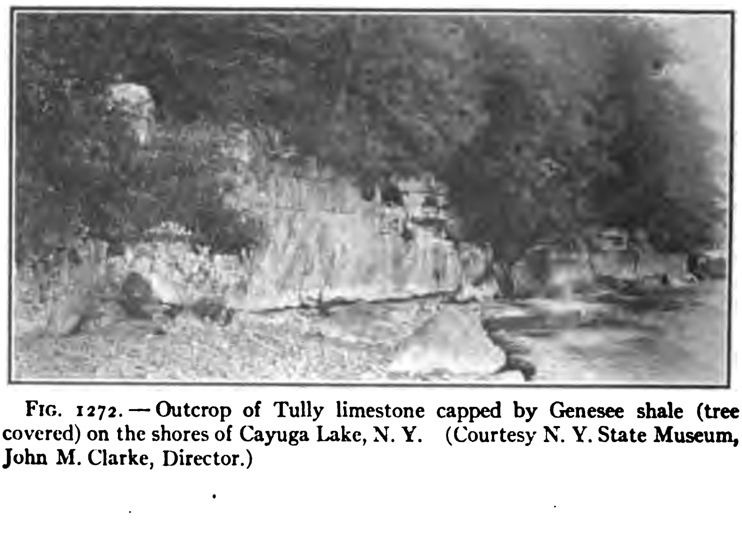


Fig. 1272. — Outcrop of Tully limestone capped by Genesee shale (tree covered) on the shores of Cayuga Lake, N. Y. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

sandstone, a beach and sandbar deposit (Fig. 1273). The Portage beds which succeed are gray and black shales in frequent alternation capped by sandstones. They are typically exposed in the gorge of the Genesee at Portage, from which locality they received their name (Figs. 1274–1276). Among the characteristic fossils are goniatites (Fig. 1277) and small pelecypods. Eastward they are replaced by the Ithaca beds, which carry a distinctive fauna (Fig.

Fig. 1273. — Portion of a fossil beach of Devonian time (Sherburne sandstone), showing depressions left in the surface by plants (?) *Fucoides graphica*, and a goniatite shell. (After John M. Clarke.)

1278). The last division is formed of the *Chemung* sandstone and shales, which here replace the Catskill beds. Among the many fossils of this series *Spirifer disjunctus* (Fig. 1279 *e–f*) may be noted. These Upper Devonian rocks also carry the peculiar cone-in-cone structures, the origin of which is not fully understood (Fig. 1280).

Analysis and Comparison. — The Helderberg beds are absent from western New York. If ever deposited there, they were eroded again during Oriskany time. The sands spread over the erosion surface are occasionally injected downward in the Silurian rocks into fissures, the characters of which suggest that they were formed by early Devonian earthquakes before the Onondaga limestone was deposited (Fig. 591, p. 689, Pt. I). The Onondaga limestone shows by its reef structure that the waters were pure

FIG. 1274. — Typical exposure of the lower Portage shales in the Genesee gorge near Mount Morris, N. Y. The sloping banks are formed by the Cashaqua gray shales with goniatites, etc. The upper part of the bank in the distance is formed by the Rhinestreet black shale, with fish remains. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

and warm. In the lagoons between the reefs silica-secreting organisms (Radiolaria, sponges, etc.) lived, and from their deposits much chert was formed secondarily (Fig. 1168, p. 324). This coral-reef limestone can be traced across the state of New York in one direction, westward to Ohio and Michigan, in another, and southward to Kentucky, having everywhere much the same character, *i.e.*, that of a coral limestone. It is abruptly followed by the black Marcellus shale which thins away in Ohio, but is thick in the Appalachian trough where the Onondaga limestone is absent. An east-west section in New York State reveals the following relationship (Fig. 1281):

In the Appalachian trough, in Maryland, only black shales are found. At Buffalo both limestone and shale are present, while in Michigan only the limestone occurs. The shale, an eastern formation, progressively replaces the higher parts of the limestone west-

FIG. 1275. — Cliff of upper Portage shales and flagstones (Gardeau beds) exposed in the gorge of the Genesee River between the Middle and Lower Falls at Portage, N. Y. — the type locality. The chief fossils in these beds are goniatites and pelecypods (Figs. 1317 *j*, *m*, *n*), similar to those of the Cashaqua shales. These fossils are found only in certain layers. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

ward, the two merging; they are contemporaneous deposits. We have here such a series as is forming to-day in the Florida reef region, where the older reefs are progressively covered by muds rich in decaying organic matter (see *ante*, p. 300, Pt. I). It is essentially the Utica shale-Trenton limestone relation of the Ordovician repeated in the Devonian and, as the Utica was the source of the Trenton oil, so the Marcellus is the source of the Onondaga oil of Canada and elsewhere. This product of distillation from organic

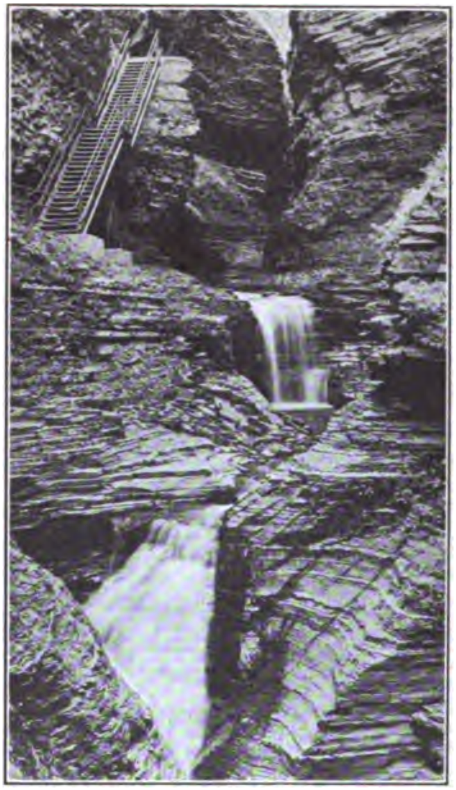


FIG. 1276. — Upper Devonian sandstones and shales (Portage formation) exposed in the gorge of Watkins Glen, N. Y.

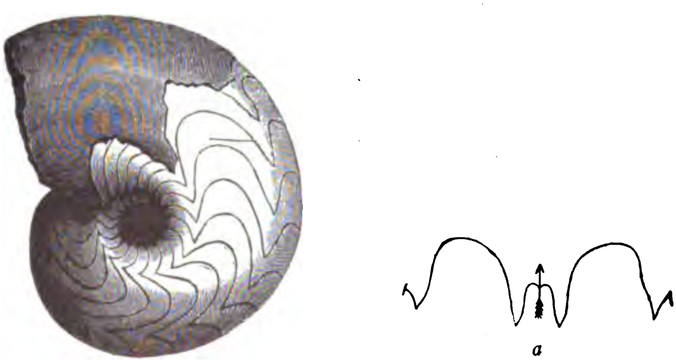


FIG. 1277. — *Goniatites* (*Manticoceras*) *intumescens*, an Upper Devonian goniatite; *a*, suture-line. (After Kayser.)

Fig. 1278. — Portage beds (typical Ithaca phase); shales and sandy beds, exposed in the gorge of Fall Creek, Flume Falls, Ithaca, N. Y. (Courtesy N. Y. State Museum, John M. Clarke, Director.)

matter passes laterally from the shale, where it originated, into the limestone, where it was stored.

The Hamilton beds of western New York are marine throughout, the non-marine upper beds (bluestone) of the east having become merged into the marine sediments. The limestone beds of the Hamilton in western New York are merely the attenuated members of the great limestone series which almost entirely replaces the

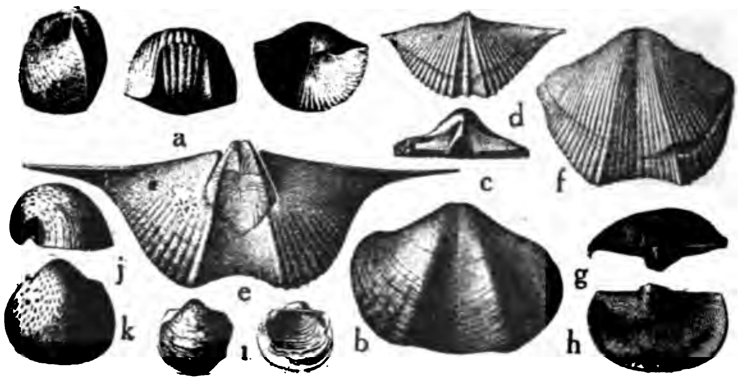


FIG. 1279. — Upper Devonian brachiopods. *a*, *Hypothyris cuboides*, 3 views, Tully; *b–c*, *Spirifer* (*Reticularia*) *lævis*, pedicle valve with apical view, Portage; *d*, *Spirifer mesicostalis*, Ithaca-Chemung; *e–f*, *Spirifer disjunctus*: *e*, internal mold of long-winged form showing characteristic division by dental plates; *f*, exterior of short-winged pedicle valve, Chemung; *g–h*, *Schuchertella chemungensis*, apical view, and pedicle valve, Chemung; *i*, *Productella hallana*, opposite views, western Upper Devonian; *j–k*, *Productella speciosa*, two views of pedicle valve, Portage, Chemung, Kinderhook.

shales of this period in Michigan. Thus we have here an ideally graded formation, — sandy shales and sandstone, partly non-marine with plants in the east near the shore; calcareous shales rich in marine fossils farther west; and limestones with coral reef structures in the open sea a thousand miles or more from the shore (Figs. 1282, 1283 *a*, *b*).

In central New York the Hamilton is followed conformably by the Tully limestone which becomes a layer of iron pyrites in the west. Traced southward to Pennsylvania this limestone is progressively replaced by the black Genesee muds, the higher members of which overlie the Tully limestone in New York. This corresponds precisely to the replacement of the Onondaga limestone by the Marcellus shale. It means that pure open water existed in the north, while muds were washed in from the south, and these muds spread northward, replacing the limestone (Fig. 1284). Over the interior of North America the Middle and Upper Devonian beds are separated by an erosion interval, which shows

FIG. 1280. — Cone-in-cone structure from the Upper Devonian of southwestern New York. The large specimen shows a fragment of rock from above with concentric lines marking outlines of cones. Two of the cones have been removed, leaving funnel-form depressions. One of the cones thus removed is shown in the lower left-hand figure. The larger cone is from another larger group. (Photograph by B. Hubbard from specimens in Columbia University Geological Museum.)

that at the end of Hamilton time the sea withdrew for a while. Sometimes nearly or quite the entire Hamilton series has been removed again by erosion, and after that black muds were spread over

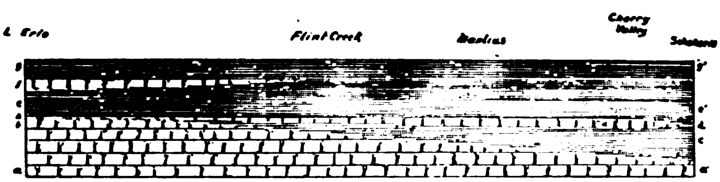


FIG. 1281. — East-west section in New York State, showing the replacing relationship of the Marcellus shale on the east and the Onondaga limestone on the west. *a*, *a'*, *b*, Onondaga limestone; *c*, lower Marcellus shale; *d*, *d'*, limestone with *Agoniatites*; *e*, *e'*, middle Marcellus shale; *f*, Stafford limestone; *g*, *g'*, upper Marcellus shale. (After J. M. Clarke.)

the eroded surface, these reaching a thickness of 600 feet in Ohio (*Ohio shale*). It is these black muds which send fingers eastward to interlock with the green and gray muds of the east, as is shown

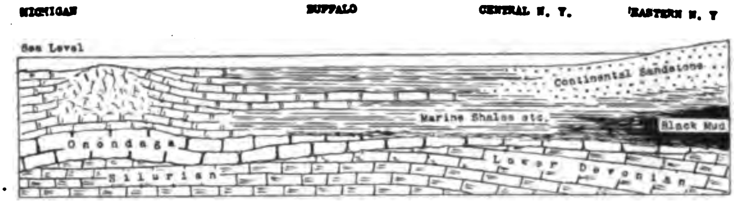


FIG. 1282. — Ideal section from eastern New York to Michigan, showing the change in facies of the Middle Devonian (Hamilton) strata from delta sands with plant remains on the east, to coral-reef rock on the west. (Original.)

by the alternation of black and gray muds in the western New York section. Again it is these black muds of Ohio, Indiana, and Michigan which in all probability were the source of the petroleum

a *b*

FIG. 1283. — Devonian reefs of Attawapishkat River, Canada. *a*, Reefs covered by bedded strata shown in river bank; *b*, a single reef mass modeled out by erosion. (After Bell from *Principles of Stratigraphy*.)

which was stored in the interbedded sandy layers of the Upper Devonian of western New York and Pennsylvania, and has been so extensively exploited in the Olean-Bradford region. The east-

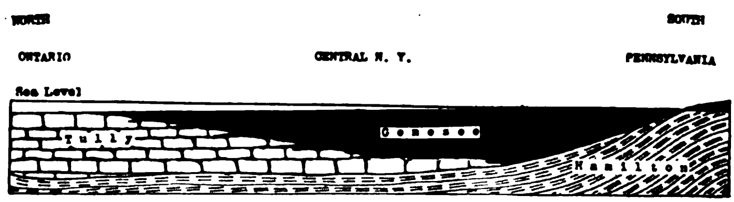


FIG. 1284. — Diagrammatic section, showing the replacing relationship of the Genesee shale and Tully limestone as originally deposited. (Original.)

west relation of this series is diagrammatically represented as follows (Fig. 1285):

Comparing the sections of eastern and western New York, we note that the Upper Devonian beds of the east are all continental, becoming increasingly red toward the top. In western New York they are all marine with no red beds in the Devonian. Between

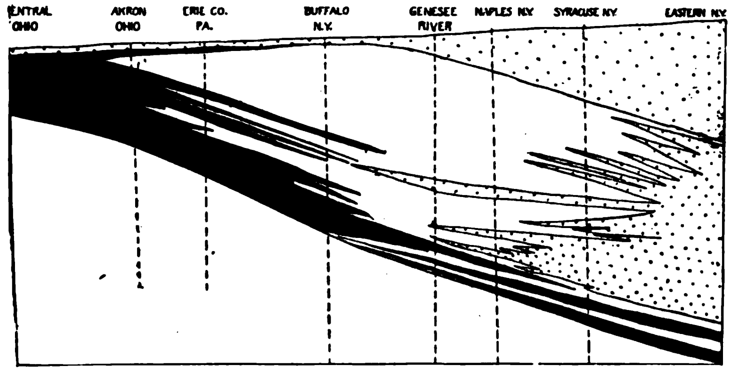


FIG. 1285. — Diagrammatic section from the Catskill region of eastern New York to Ohio, showing the relationships and relative thicknesses of the Upper Devonian formations, and the interfingering of the black shale (black) from the west with the green shales (white) and the sandstones from the east. (Original.)

these two sections we find marine beds at the base and continental beds at the top. The following diagram shows this relationship (Fig. 1286). The interpretation is as follows: In the Appalachian trough of New York and Pennsylvania sands and muds were built

FIG. 1286. — Diagram showing the relationships of the Upper Devonian marine and continental formations in the state of New York. (Original.)

into alluvial fans by rivers from Appalachia. In the center of the trough and westward, marine conditions prevailed and the finer sands and muds were deposited there, enclosing marine organisms. The rivers became more intermittent and the climate drier, so that the higher sands could be oxidized, as a result of which, they are red beds to-day. These red Catskill beds gradually spread westward and progressively replaced the marine Chemung beds, this being another example of replacing overlap.

The Devonian History of North America

At the opening of Lower Devonian time, the seas were restricted to the Appalachian trough, which apparently was closed on the south. An epeiric sea probably lay in the Cordilleran trough as well, though we know little as yet of the formations in that region. The Appalachian trough (Fig. 1287) opened to the Atlantic on the northeast (Gaspé region), and organisms from the Atlantic entered its waters. Other organisms, surviving in the trough from Monroan time, became modified under the restricted environment produced by the shrinking of the seas, and from these two sources the Helderberg fauna was developed. Most of the species were probably developed within the trough from survivors of the Silurian fauna, just as a special fauna has developed in the Red Sea to-day from ancestors which had entered it from the Indian Ocean. Over the interior of North America erosion was going on, but the rivers of Appalachia appear to have been little active. At the end of Helderbergian time the sea withdrew to the Atlantic (Fig. 1288), leaving the trough dry and subject in places to erosion, so that much, and sometimes all, of the Helderberg deposits was removed again, though locally the product of this erosion accumulated in depressions, and from this material the Port Ewen beds were formed. At the same time deposition continued near the mouth of the trough, forming the thick series at Gaspé. Meanwhile sands from various sources, chiefly erosion of older sandstones (Sylvania, St. Peter, or basal sandstones), were spread over the eroded land surfaces, probably largely by the wind, so that when the trough was flooded again (Fig. 1289) and the waters spread westward over the eroded surface, they found quartz sands, sometimes in thick deposits in hollows, at other times in thin layers. These sands were more or less reworked by the waves, and the animals of the sea contributed their shells to the deposit, which in places became very fossiliferous. Thus was formed the Oriskany sandstone, which in parts of Pennsylvania is a thick and very pure quartz-sand (Fig. 485, p. 578, Pt. I), but in other regions is often only a thin layer of quartz grains. The typical Oriskany fauna entered the trough from the Atlantic, but the Arctic sea, the

FIG. 1287. — Palæogeographic map of North America in Helderbergian time, showing the distribution of land and water (black) at the opening of the Devonian. (Original.)

home of coral growth, also advanced southward. In that sea the old Upper Silurian fauna had become modified and it now returned to the North American continent as the Onondaga fauna, and coral reefs once more began to grow in central North America (Figs. 1290, 1291). By this time the rivers of Appalachia had become active again. At first they spread mud deltas into the waters, thus forming the Esopus-Schoharie muds. Then followed the Marcellus muds, which slowly spread westward, extinguishing

FIG. 1288. — Palæogeographic map of North America in early Oriskany time, showing the distribution of land and water (black), and the type of drainage. (Original.)

the coral-reef growth as they advanced. At last only a remnant of the Onondaga fauna remained in the interior sea, but now the

Atlantic fauna entered again, and from these two sources the Hamilton fauna was developed. This spread, as the waters again

FIG. 1289. — Palæogeographic map of North America in late Oriskany time, when the Appalachian trough was again flooded. (Original.)

deepened, over the region of the black muds of the preceding epoch (Fig. 1292). Meanwhile, the Cordilleran sea had spread eastward, its waters having become populated by immigrants from Asia

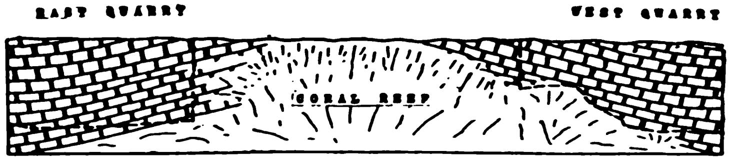


FIG. 1290. — Diagrammatic section of the Middle Devonian coral reef exposed on the north face (inface) of the Onondaga cuesta near Williamsville in western New York. (Original.)

FIG. 1291. — Palæogeographic map of North America in Onondaga time, showing the distribution of land and sea (black). (Original.)

by way of Alaska, as is clearly shown by the distribution of the fossils in these beds. These waters bearing the Asiatic fauna

FIG. 1292. — Palæogeographic map of North America in Hamilton time, showing the distribution of land and sea (black). (Original.)

effected a junction with the eastern waters in the region of Wisconsin and Michigan, and we find there to-day that the beds contain the mingled faunas of the two series. For a long time the continent was now covered by pure warm seas in which coral reefs grew, but the impending change was heralded by the fact that the Appalachian rivers became more and more loaded with sediments, so that the deposits which they spread out eventually rose above the surface of the sea as the Ashokan bluestone delta.

At the close of Meso-Devonian time the seas shrank, this being coincident with a further rise of Appalachia, and an increase in

FIG. 1293 *a.*—*Bothriolepis canadensis*, restoration; upper side. (After Patten, *Evolution of the Vertebrates;* by permission of Blackiston's Sons and Co.)

the quantity of mud and sand brought to the delta by its rivers. A second great delta was built into the northern part of the Appalachian trough, and its remains are now seen in the great Devonian sandstones of the Gaspé region in which have been found the wonderfully preserved bony armors of the ancient fish-like ostracoderms (Fig. 1293).

While this was going on, and probably earlier, while the Hamilton fauna still flourished in the interior seas of New York, the Ohio and Michigan region and that now included in our southern states (Tennessee, Alabama, Kentucky, Missouri, etc.), were the site of the formation of a remarkable black soil, comparable in all respects to the black earth or tchernosem of modern Russia (see *ante*, p. 459, Pt. I). This was partly residual earth and partly a loessic deposit, as its Russian analogue is believed to be, and the growth and decay of herbaceous vegetation gave this soil its heavy quantum of organic matter. This soil was gathered from certain

FIG. 1293 *b*. — *Bothriolepis canadensis*, restoration; under side. (After Patten, *Evolution of the Vertebrates;* by permission of Blackiston's Sons and Co.)

sections by rivers and washed into the sea which lingered in the north, just as the Vistula to-day washes the black Russian earth into the Bay of Danzig. Much of the old soil, however, remained where it was formed, resting on a foundation of various older rocks, Silurian or Ordovician. The first of the rivers which washed black mud into the now contracted Upper Devonian sea formed the Genesee shale (Fig. 1294). As the sea spread westward in Portage time (Fig. 1295), black muds were washed into it in the regions now embraced in the states of Ohio, Indiana, and Illinois, and these muds spread northward to Michigan. In this way we can readily explain the origin of the Ohio black shale, which inter-

Fig. 1294. — Palæogeographic map of North America, showing the distribution of land and water (black) at the time the Tully limestone and Genesee shales were being deposited, *i.e.* the opening of Upper Devonian time. (Original.)

fingers eastward with the sediments from Appalachia. It should be noted, however, that this shale has also been interpreted as having been formed on the bottom of stagnant water bodies like those of the Black Sea. In these black muds were included the remains

FIG. 1295. — Palæogeographic map of North America, showing the distribution of land and water (black) in Portage time. (Original.)

of the early coniferous trees, fragments of the trunks of which, many feet in length and a foot or more in diameter, are not infrequently found. These trees may have grown on the banks of the rivers which brought the mud. The remains of huge sharks and of fish related to our modern lung fish are also found in these muds (Fig. 1296). They were probably inhabitants of the rivers which brought the mud, rather than dwellers in the sea, as their remains are most abundant in these mud deposits. Marine organisms are rare, probably because the waters were too fresh near the mouths of the rivers to permit their existence. The case is

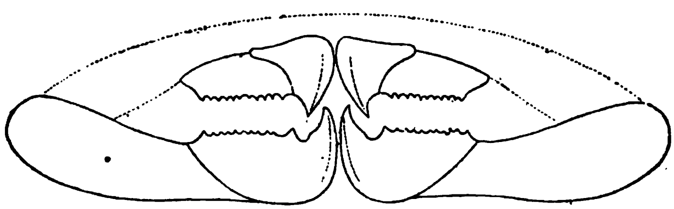


FIG. 1296. — Outlines of jaws of a Devonian fish. *Dinichthys hertzeri*, Ohio black shale about $\frac{1}{8}$ natural size.

analogous to that of the Baltic Sea of to-day, where few shell-building organisms live, while those that do occur are dwarfed, as are the few shells found in the Ohio shales.

Continued river activity in the east resulted finally in the spreading over considerable territory of the sands and muds of the Catskill delta (now red), while the black muds spread from the south, so that by the close of Devonian time much of the territory once covered by normal marine waters had become dry land or marshy, with brackish-water lagoons and bays. By the opening of the next period, however, the marine waters spread again in all directions.

EUROPE AND ASIA

With the folding of the Silurian and older rocks in the Welsh and Scottish regions of the Baltic geosyncline, the zone of maximum marine deposition appears to have been moved eastward, so that we find the oldest marine Devonian rocks in western Germany. These rocks were folded again in more recent times, and through them the Rhine has finally cut its beautiful gorge (Fig. 601, p. 703, Pt. I). Therefore it is on the banks of the Rhine, especially near Coblenz on the north and at the southern end of the gorge as well, that we meet with these oldest Devonian rocks (Fig. 1297), while between these points higher Devonian strata are shown. Another development of them is found in Bohemia, where they succeed the Upper Silurian beds conformably. The rocks of the Rhine gorge are several thousand feet thick and are mostly shales and

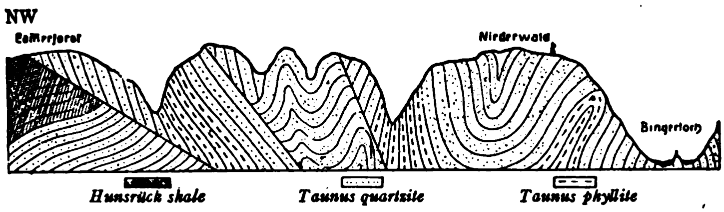


FIG. 1297. — Section of deformed Lower Devonian strata exposed in the walls on the Rhine gorge, near Bingen. (Modified after Holzapfel.)

sandstones with marine fossils. The geosyncline in which they were formed apparently communicated with the Atlantic, for many of the fossils of these rocks have near representatives in the Helderberg and Oriskany deposits of the Appalachian trough. The Bohemian Lower Devonian fauna is, however, more distinct and probably represents an independent development in a separate province. The folded Silurian strata of England and southern Scotland were, at this time, subject to erosion, and the product of this erosion was deposited in alluvial fans and river flood-plain strata. This was the beginning of the formation of the Old Red Sandstone series which represents practically the whole of the Devonian, and is throughout a formation of continental origin. (Fig. 1298).

FIG. 1298. — Vertical strata of upper Old Red Sandstone, Sandtop Bay, Caldy Island, Pembrokeshire, England. (Photo Geological Survey, Great Britain; from Lake and Rastall.)

Over many parts of Scotland it rests unconformably upon the

FIG. 1299. — Upper Old Red Sandstone conglomerate, resting unconformably on the upturned edges of the Silurian greywackes. Sickar Point, near Cockburnspath, Scotland. (Photo by M. I. Goldman.)

FIG. 1300. — Contact of the upper and lower Old Red Sandstone at Whiting Ness (Arbroath), Scotland, showing unconformity between them. (Photo by M. I. Goldman.)

Silurian rocks (Fig. 1299), while elsewhere, and in the Orkney Islands, the upper Old Red lies unconformably on the lower (Figs. 1300, 1301). Its chief fossils are fish, ostracoderms (Figs. 1338–1344), eurypterids, and occasionally plant remains. Fresh-water mussels also occur in some strata. Continental red beds of Lower Devonian age were also formed in southern Russia (Podolia), where they are to-day exposed in the banks of the Dniester River. They grade downward into the subjacent Upper Silurian deposits of that region. In the Baltic Provinces of western Russia beds of the Old Red Sandstone type were also formed by rivers coming from the land mass on the northwest, and were spread over a considerable area during Meso- and Neo-Devonian time.

FIG. 1301. — Old Man of Hoy, Orkneys, upper Old Red Sandstone resting unconformably upon the lower. (After Geikie.)

In Meso-Devonian time the sea extended over a considerable portion of western Europe, and extensive coral-reef limestones accumulated. These seas spread eastward across Asia where, as the result of the elevation of the Irkutsk basin, marine sedimentation became confined to the areas involved in the new geosyncline farther south (p. 216). This Trans-Asiatic sea, finally, communicated with the northern end of the Cordilleran geosyncline, so that the faunas which then lived in the waters of Europe and Asia could also enter the west American geosyncline and spread eastward to Iowa and Wisconsin.

A comparison of the Upper Devonian faunas of Asia with those of western North America, *i.e.*, of the Cordilleran geosyncline and its eastward extension, shows that a very close similarity exists between them, and this can only mean that the two regions continued to remain in communication. But we have seen that the brachiopod and coral fauna of the Cordilleran region is very distinct from that which characterizes the Upper Devonian rocks of western New York, Ohio, and Pennsylvania, in which pelecypods and goniatites predominate. This fauna appears suddenly in North America as an invasion of the central region at the close of Hamilton time, whereas the western (Iowan) fauna is clearly derived from the preceding Middle Devonian of that region. In the Atlantic region the Hamilton fauna continued to exist, as is shown by the repeated invasions of this fauna into the eastern New York and Pennsylvania region. On the south land masses existed from which the rivers spread muds northward. Thus this goniatite-pelecypod fauna could enter North America only from the north, or northwest perhaps, along the old pathway of communication across the Arctic region. The development of this fauna seems to have taken place in Europe, where these goniatites form a characteristic feature of the Upper Devonian strata.

Southern Continents

Northern Africa was submerged in Devonian time by a portion of the sea which covered Europe, as is shown by the fact that Devonian rocks, with fossils like those found in the Devonian of Europe, crop out at various places in the northern Sahara desert. In South Africa (Capeland), on the other hand, we find Devonian strata with the Atlantic fauna, and the same is true on the other side of the Atlantic in South America, where Devonian formations are known from Brazil, Bolivia, Argentina, the Falkland Islands, etc. These probably represent deposits formed in embayments of the Atlantic. Thick deposits of Devonian strata are also found in Australia, especially in the southeastern portion.

Disturbance and Volcanicity

The Devonian strata of the New England States and the maritime provinces of Canada have been strongly disturbed by mountain-making processes, which, in some cases, appear to have been inaugurated in Middle Devonian time and were completed before the opening of the Mississippian of that region. Thus we find that throughout Nova Scotia, New Brunswick, and southern Quebec, the Mississippian and Pennsylvanian rocks rest unconformably upon the folded and eroded older formations. Associated with these disturbances was the extensive intrusion of igneous masses into the older rocks, and probably the outpouring of lavas.

In western Europe, too, extensive disturbances took place during early Devonian time, when the Caledonian chain of mountains was formed by the folding of the older rocks. At this time,

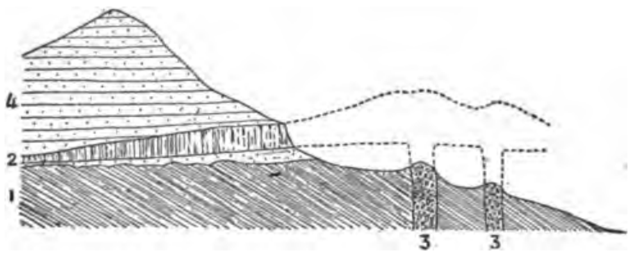
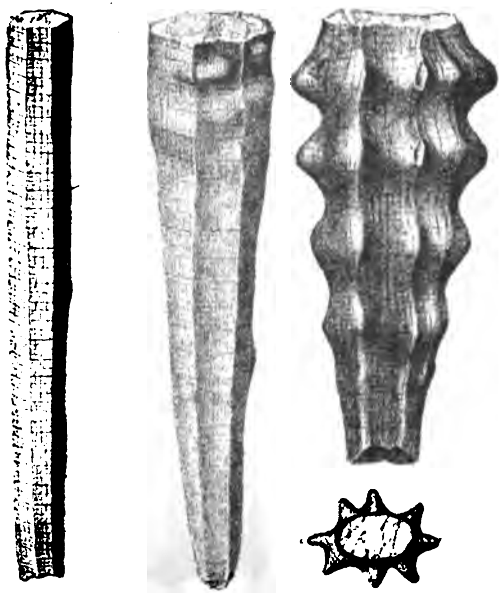


Fig. 1302. — Cross section of a Devonian volcano, Hoy, Orkneys. (After A. Geikie.) 1, Caithness shales (lower Old Red Sandstone); 2, lava sheet; 3, volcanic necks full of an agglomerate of ejectamenta; 4, upper Old Red Sandstone.

too, enormous overthrusts occurred in what is now the Scottish Highlands and western Scandinavia, and associated with these disturbances there was much outpouring of lava, so that in some districts of Scotland the Old Red Sandstone is formed largely of lavas and agglomerates, while in other parts the lower Old Red contains extensive lava-flows (Figs. 1301, 1302). Similar lava-flows are intercalated in the marine Devonian series of southern England.

General Characteristics of the Devonian Faunas and Floras

While the life of the Devonian has many characteristics in common with that of the Silurian, there is, nevertheless, a marked distinction. The most characteristic **sponges** are the Dictyospongidæ (Fig. 1303). **Graptolites** have disappeared entirely except for members of the *Dictyonema* group, which are found occasionally. **Stromatoporas**, on the other hand, have become exceedingly abundant, and sometimes form masses up to 10 feet in diameter (Fig. 1304). The **cup-corals** were in their acme of development, and a great array of types characterizes the Devonian reef rocks. The most conspicuous were the genera *Zaphrentis* (Figs. 1254, 1305), *Cyathophyllum* (Figs. 1306 *c–d*), *Heliophyllum* (Figs. 1306 *f*, 1307 *a*), *Cystiphyllum* (Figs. 1306 *a*, *b*), etc., and in Europe the operculated *Calceola* (Fig. 1308). Compound forms also abounded, the genera *Prismatophyllum* (Fig. 1307 *b*) and *Phillipsastræa* (Fig. 1309) being most



a b c

FIG. 1303. — Types of Devonian Dictyospongidæ. *a, b, Prismodictya prismatica*, two varieties; *c, Hydnoceras tuberosum*, with end view. (I. F.)

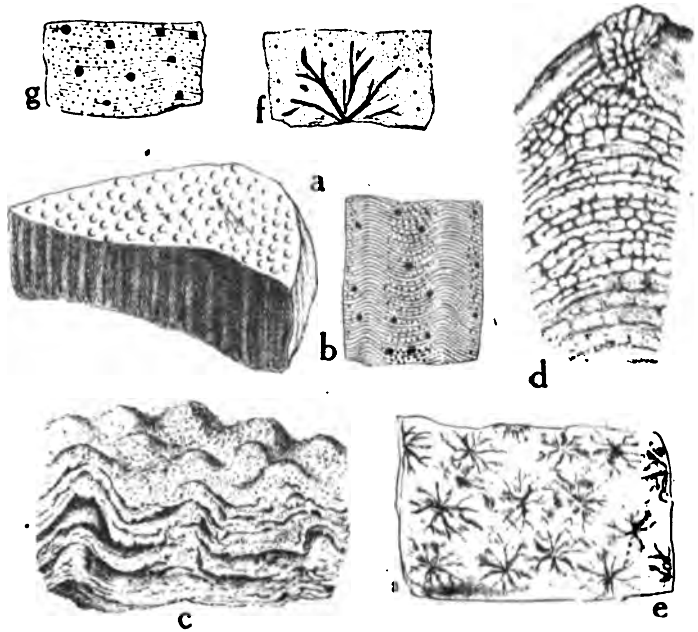


FIG. 1304. — Devonian stromatoporoids. *a, Stylodictyon columnare*, Onondaga and Hamilton; *b*, vertical section enlarged showing the dense structure of the vertical "rods"; *c, Stromatoporella tuberculata*, Onondaga; *d, S. granulata*, Hamilton; *e–g, Syringostroma densum*, Onondaga: *e*, surface view showing the astrorhizæ; *f*, horizontal section enlarged; *g*, vertical section enlarged. (I. F.)

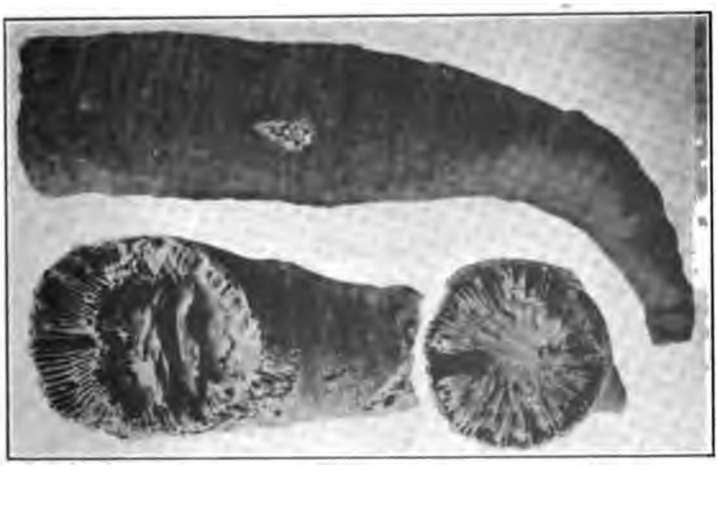


FIG. 1305. — *Zaphrentis gigantea*. Onondaga. Reduced. (After Rominger.)

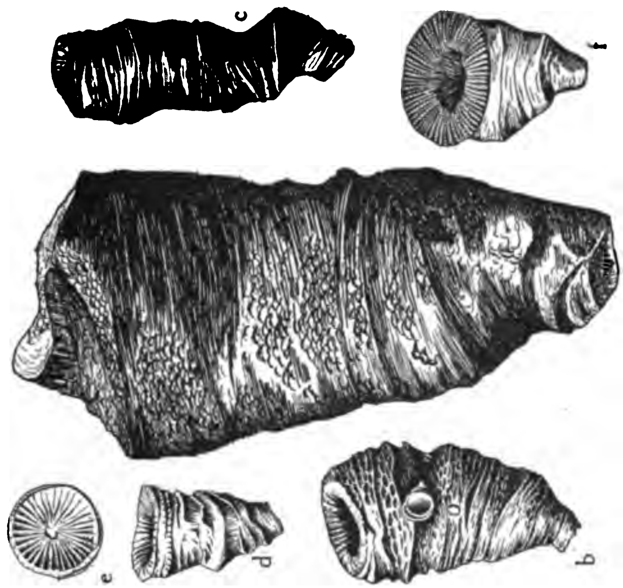


FIG. 1306. — Middle Devonian (Hamilton) corals; *a*, *Cystiphyllum vesiculosum*, ½ natural size; *b*, *C. varians*; *c*, *C. conifollis*, reduced; *d*, *Cyathophyllum conatum*, reduced; *e*, calyx of the same; *f*, *Heliophyllum halli*, reduced. (I. F.)

FIG. 1307 *a*. — *Heliophyllum confluens*. Middle Devonian. (I. F.)

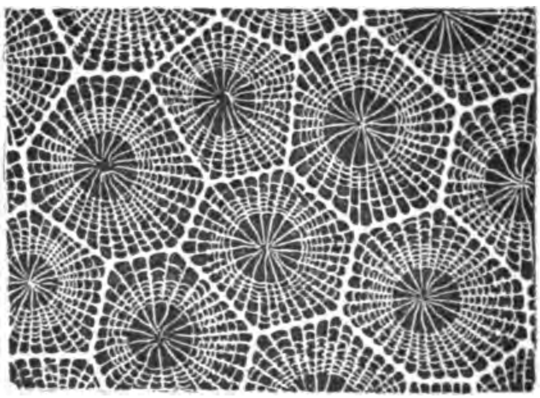


FIG. 1307 *b*. Section of *Prismatophyllum davidsoni*. Middle Devonian.

FIG. 1308. — *Calceola sandalina*. A Devonian coral the calyx of which is closed by an operculum. (After Kayser.)

FIG. 1309. — *Phillipsastræa (Billingsastræa) gigas.* Onondaga. (After Rominger.)

FIG. 1310 *a*. — *Favosites tuberosus.* Onondaga. (After Rominger.)

FIG. 1310 *b*. — *Favosites nitella.* Hamilton. (After Rominger.)

FIG. 1310 *c*. — *Cladopora cryptodens.* Onondaga. (After Rominger.)

frequently noted. *Favosites* (Fig. 1310 *a, b*) was represented by numerous species, and the related *Michelinia* (Fig. 1311) was also widespread.

Bryozoa were common, especially the fenestelloids (Fig. 1313). The **Brachiopoda** were also represented by characteristic types. The *Orthis* group comprised the short-hinged round forms (*Rhipidomella*, Fig. 1314 *e*; *Schizophoria*, Fig. 1314 *f*), etc. The flat-shelled or concavo-convex types included the genera *Stropheodonta* (Figs. 1314 *a, b*), *Strophonella* (Fig. 1314 *c*), *Schuchertella* (Fig. 1314 *d*), and the spine-bearing *Chonetes* (Figs. 1315 *d, j, k*), which were common for the first time. *Spirifer* was extremely abundant and often very long-hinged (Figs. 1258 *a*, 1314 *g–j*). Other characteristic genera were *Athyris* (Figs. 1315 *l, m*), *Atrypa* (Figs. 1314 *l–n*), *Meristella* (Fig. 1256 *a*), and a number of rhynchonelloid types. A characteristic feature of many Devonian

FIG. 1311. — *Michelinia convexa*. Onondaga. (I. F.)

FIG. 1312. — *Aulopora serpens*. Middle Devonian. (After d'Orbigny.)

brachiopods should be noted: their soft "arms" or brachia were supported by calcareous spirals, which are commonly preserved in the interior of the shell (*Spirifer*, Fig. 1506, *Athyris*, *Atrypa*, etc., Figs. 871, 873, pp. 114–115). A typical Middle Devonian brachiopod of Europe, Asia, and western North America is *Stringocephalus* (Fig. 1316). **Pelecypods** were numerous, especially the winged *Pterinea* (Figs. 1259, 1317 *e–g*), *Grammysia* (Fig. 1317 *b*), *Buchiola* (Fig. 1317 *n*), etc. **Gastropods** were very generally represented by loose-coiling types (*Platyceras*, Figs. 1318 *g–n*); but others, especially *Pleurotomaria* (Fig. 1318 *a, b*) were also common. Among **cephalopods** the most characteristic were the goniatites (Figs. 1321 *d*–1323), though their shells are not everywhere present in the Devonian rocks. Other cephalopods were *Orthoceras* (Fig. 1319) and *Nautilus* (Fig. 1321 *c*). The **echinoderms** were chiefly represented by crinoids (Fig. 1328), but some blastoids also occurred (*Elæacrinus*, Fig. 1327). **Starfish** of relatively simple structure were common in some cases.

Among the **trilobites** the Silurian genus *Dalmanites* still continued in the Lower Devonian, but the most characteristic genera were *Proëtus* (Fig. 1330), *Phacops* (Fig. 1258 *d*), and *Cryphæus* (Fig. 1331). *Homalonotus* (Fig. 1332), though represented in the Silurian, is also a typical Devonian genus. There

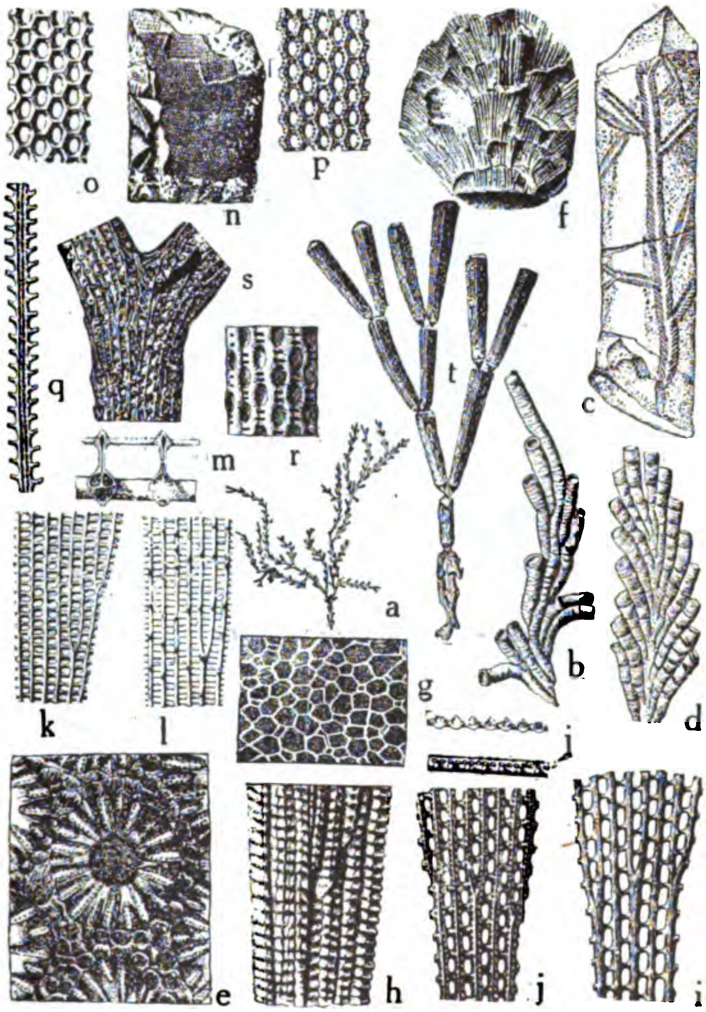


FIG. 1313. — Devonian Bryozoa. *a–b*, ***Hederella canadensis*** with enlargement (×9), Onondaga and Hamilton; *c–d*, ***Reptaria stolonifera*** with enlargement (×4½), Hamilton; *e*, ***Botryllopora socialis***, much enlarged, Hamilton; *f–h*, ***Monotrypa tabulata***: *f*, a fragment (×¾); *g*, tangential section (×4½); *h*, group of tubes enlarged showing corrugations, Helderbergian; *i–j*, ***Fenestella emaciata***, opposite sides of frond (×3), Hamilton; *k–m*, ***Unitripa scalaris***, opposite sides of frond (×3), and transverse section much enlarged, Hamilton; *n–p*, ***Loculipora perforata***: *n*, fragment (×¾); *o*, celluliferous side (×3); *p*, non-celluliferous side (×3), Hamilton; *q*, ***Pinnatopora carinata*** (×4½), Hamilton; *r*, ***Streblotrypa hamiltonensis*** (×13½), Hamilton; *s*, ***Cystodictya incisurata***, enlarged, Hamilton; *t*, ***Acrogenia prolifera*** (×¾), Hamilton. (I. F.)

were many characteristic **ostracods** (Fig. 1334), but they seldom formed the dominant element of the fauna, as they often do in the Silurian. The presence of **worms** is indicated by small calcareous tubes (*Spirorbis*) and by conodonts (Fig. 1335).

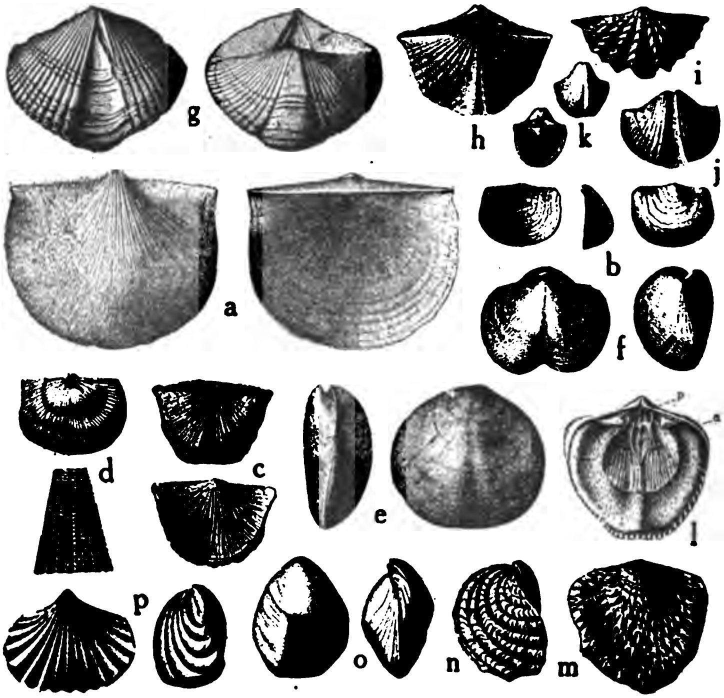


FIG. 1314. — Characteristic Devonian brachiopods. *a*, *Stropheodonta demissa*, opposite views, Hamilton; *b*, *Stropheodonta* (*Pholidostrophia*) *iowaensis*, Onondaga and Hamilton, 3 views; *c*, *Strophonella reversa*, Chemung, opposite views; *d*, *Schuchertella arctostriata*, with enlargement of surface, Hamilton; *e*, *Rhipidomella vanuxemi*, Hamilton, 2 views; *f*, *Schizophoria striatula*, Middle and Upper Devonian, 2 views; *g*, *Spirifer fornacula*, Hamilton, 2 views; *h*, *Spirifer consobrinus*, Hamilton; *i*, *Spirifer sculptilis*, Hamilton; *j*, *Spirifer tullius*, upper Hamilton; *k*, *Ambocœlia umbonata*, Hamilton, opposite valves; *l*, *Atrypa reticularis*, interior of pedicle valve, Onondaga-Hamilton; *m*, *A. spinosa*, pedicle valve, Hamilton; *n*, *A. occidentalis*, Middle Devonian; *o*, *Cryptonella planirostris*, Marcellus-Hamilton, 2 views; *p*, *Camarotœchia sappho*, Marcellus to Waverly, 2 views.

The fresh water (river and estuarine) deposits are characterized by the remains of **crustaceans** (Fig. 1336) and **eurypterids**, among which huge forms, sometimes attaining a length of 5 feet, are known, though only from fragments (*Stylonurus*, Fig. 1337). The **fish** also appear to have been largely restricted to the rivers, although many fish-remains are found in the marine strata, generally under conditions which suggest that they represent river types which have entered the sea, or the remains of which have been carried

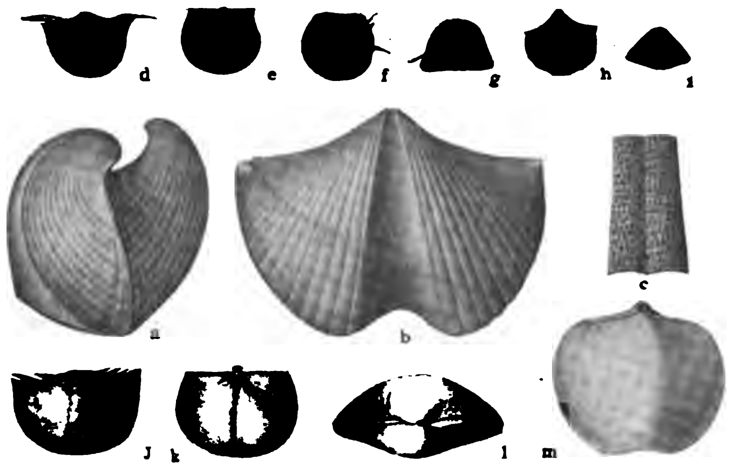


FIG. 1315. — Middle Devonian brachiopods. *a–c, Spirifer granulosus*, 2 views and enlargement of surface; *d, Chonetes mucronatus; e–g, Strophalosia truncata*, brachial and 2 views of pedicle valve; *h–i, Cyrtina hamiltonensis*, pedicle and cardinal views; *j–k, Chonetes coronatus*, exterior of pedicle and interior of brachial valves; *l–m, Athyris spiriferoides*, cardinal and brachial views. (All reduced.)

out from the rivers and buried in marine strata. Nevertheless, some forms may have lived permanently in the Devonian seas.

Most characteristic of the Devonian fish-like types were the armored **ostracoderms**, the heads and anterior parts of the body of which were covered

FIG. 1316. — *Stringocephalus burtoni* ($\times\frac{3}{4}$). A Middle Devonian brachiopod of Europe and northwestern North America. (After Kayser.)

with bony plates, and which were already well developed in Silurian and even in Ordovician time. They are particularly characteristic of the more torrential types of river deposits, such as the Catskill and Gaspé delta fans (*Bothriolepis*,

FIG. 1317. — Devonian pelecypods. *a*, ***Cymitaria angulata***, Chemung; ***b***, *Grammysia bisulcata*, and *c*, *Orthonota carinata*, Hamilton; ***d***, ***Goniophora chemungensis***, and *e*, *Pterinea chemungensis*, Chemung; *f*, *Actinopteria muricata*, Marcellus; *g*, *A. decussata*, and *h*, *Aviculopecten princeps*, Hamilton; ***i***, ***Nuculites oblongatus***, interior mold, Marcellus, Hamilton and Portage; *j*, *Pterochaenia fragilis*, Portage (Naples); *k*, *Lunulicardium acutirostrum*, Genesee; ***l***, ***Paracyclas elliptica***, Onondaga-Hamilton; ***m***, *Panenka robusta*, Portage; ***n***, ***Buchiola retro-striata***, Portage (Naples); *o*, *Sphenotus contractus*, Chemung; ***p***, ***Schizodus chemungensis***, Hamilton-Chemung; ***q***, ***Palæoncilo emarginata***, Hamilton-Portage.

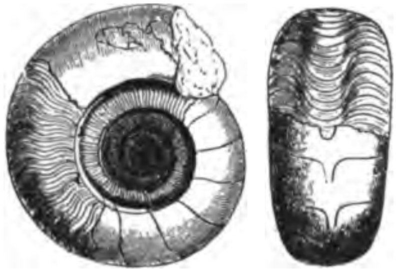


FIG. 1322. — *Anarcestes latesetatus*, a Middle Devonian goniatite of Europe. (After Kayser.)

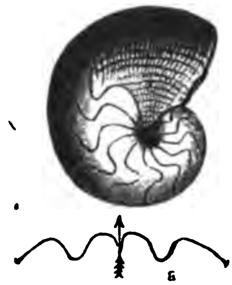


FIG. 1323. — *Tornoceras simplex*. Upper Devonian goniatite of Europe. (After Kayser.)

Fig. 1293), and the Old Red Sandstones of Europe (*Pterichthys*, Figs. 1338, 1339). These forms apparently disappeared at the end of Devonian time. With them occurred representatives of the ganoids or fish whose bodies were covered with

FIG. 1324. — *Clymenia undulata* ($\times\frac{3}{4}$). Upper Devonian ammonoid of Europc. (After Kayser.)

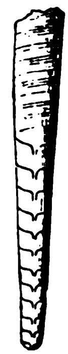


FIG. 1325. — *Bactrites elegans* ($\times\frac{1}{3}$). Upper Devonian straight ammonoid of Europe. (After Kayser.)

enameled scales, and of which modern representatives are found in the garpikes and the sturgeons. The Devonian types (*Holoptychius*, Fig. 1340; *Osteolepis*, Fig. 1341) are often beautifully preserved. Small spine-bearing sharks are also frequent in these strata.

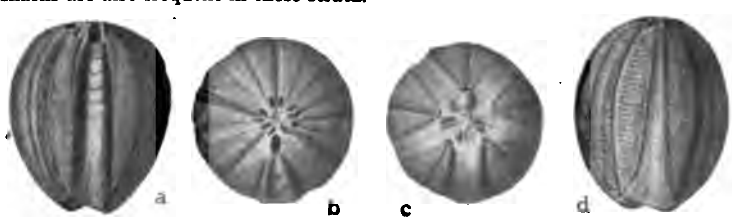


FIG. 1326. — *Elæacrinus verneuili*, a typical Middle Devonian (Onondaga), cystoid, 4 views.

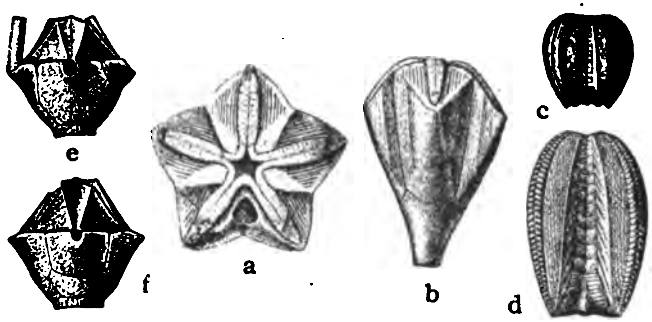


FIG. 1327. — Devonian blastoids (*a–d*) and crinoid (*e–f*). *a–b*, ***Codaster pyramidatus***, summit ($\times 2\frac{2}{3}$), and lateral view ($\times 2$), Onondaga; *c–d*, ***Elæacrinus elegans***, natural size, and one inter-ambulacrum enlarged, Hamilton; *e–f*, ***Haplocrinus clio***, opposite views of two specimens ($\times 6$), Marcellus.

FIG. 1328. — *Gennæocrinus carinatus*, 3 views of a characteristic Devonian crinoid, Hamilton ($\times \frac{1}{2}$).

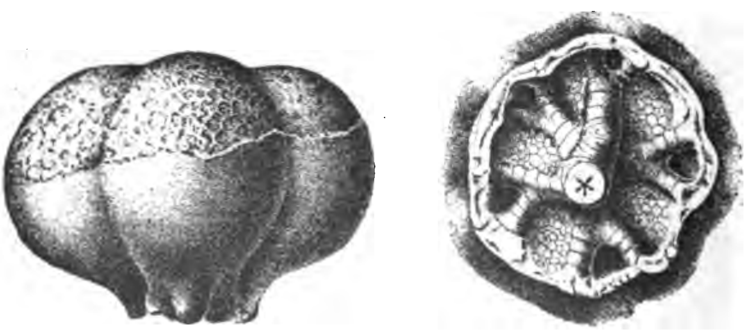


FIG. 1329. — *Camarocrinus* (*C. saffordi*), the floating bulb of a crinoid, side view and enlargement of the area of stem attachment. The genus is widely distributed in the uppermost Silurian and lowest Devonian in Europe and North America.

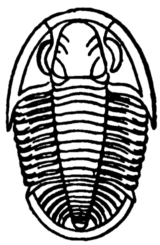


FIG. 1330. — *Proetus rowi*, a characteristic trilobite of the Hamilton group. Natural size.

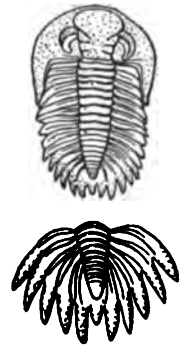


FIG. 1331. — *Cryphæus boothi*, a characteristic trilobite of the Hamilton group, with lobed pygidium. Natural size and pygidium enlarged.

FIG. 1332. — *Homalonotus dekayi*, Hamilton. (I. F.)

FIG. 1333. — *Dalmanites nasutus*, Helderbergian. (I. F.)

In the black mud deposits, formed by the rivers flowing from the flat lands, the remains of ancient lung fish (dipnoans) and arthrodires, or armored fishes with jointed necks, are found, and it appears that these inhabited the

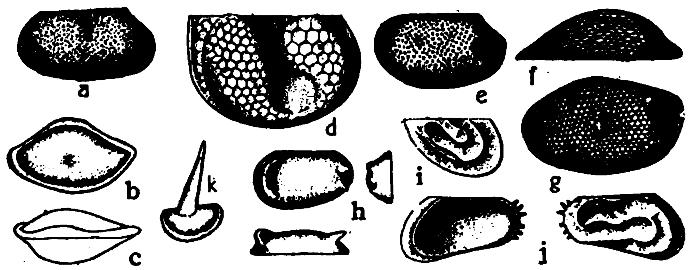


FIG. 1334. — Devonian Ostracoda, enlarged. *a*, *Isochilina fabacea* (×18), Hamilton; *b–c*, *Bairdia leguminoides*, right and ventral views (×14), Hamilton; *d*, *Primitia seminulum*, left valve (×18), Hamilton; *e–g*, *Primitiopsis punctulifera*, young, and 2 views of adult (×18), Hamilton; *h*, *Moorea bicornuta*, right and ventral views (×15), Hamilton; *i*, *Strepula sigmoides*, left valve (×18), Hamilton; *j*, *Strepula plantaris*, left valve, interior and exterior, (×18), Hamilton; *k*, *Æchmina marginata*, left valve (×14), Hamilton. (I. F.)

more sluggish rivers of the Devonian era. Probably both these groups were able to breathe air at times by means of a primitive lung-sack, as do the modern lung fish of Australian and South American rivers in times of drought. Characteristic types of Devonian dipnoans were *Dipterus* (Fig. 1342), especially

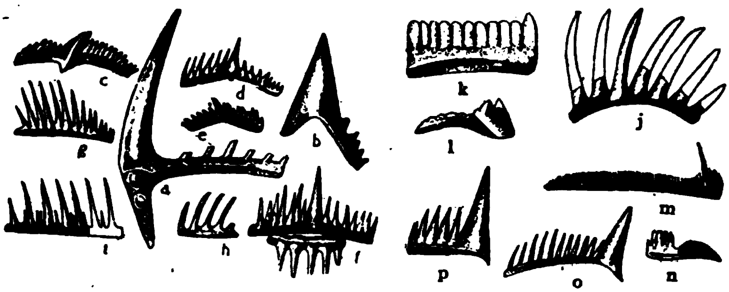


FIG. 1335. — Conodonts of the Genesee Shale. *a*, *Prioniodus panderi* (×10); *b*, *P*(?) *alatus* (×5); *c–i*, *m*, *n*, *Polygnatus dubius* (×10); *j*, *Polygnatus coronatus* (×10); *k*, *P. solidus* (×10); *l*, *P. crassus* (×10); *o–p*, *Prioniodus armatus* (×10). (I. F.)

abundant in the finer dark mud deposits of the Old Red Sandstone series of Scotland and also found in America, while arthrodires are well represented by the great *Dinichthys* or "terrible fish" of the Ohio shales, which reached a length of over 20 feet (Fig. 1296).

The fish fauna of the Devonian contained no representatives of the modern bony fishes (teleosts), but comprised ganoids (about 25 per cent), sharks

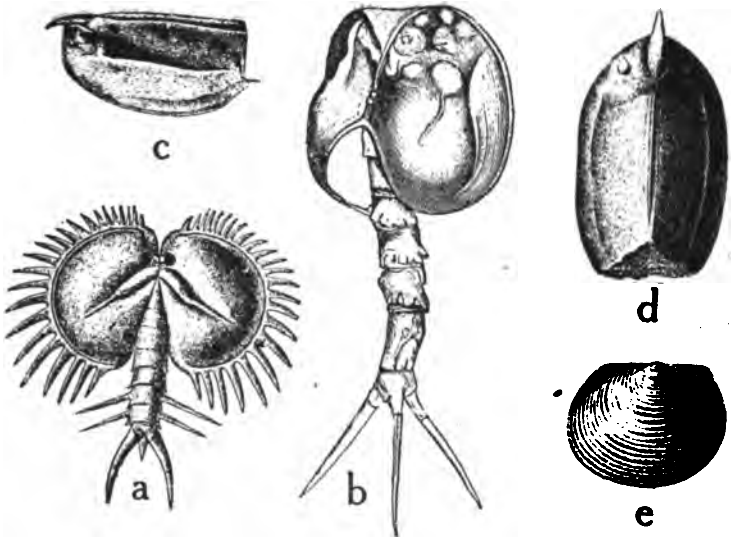


FIG. 1336. — Devonian phyllocarid crustaceans. *a*, *Pephricaris horripilata*, Chemung; *b*, *Echinocaris punctata*, Hamilton; *c–d*, *Rhinocaris scaphoptera* (*c*, left valve, *d*, both valves) Hamilton and Ithaca; *e*, *Estheria membranacea*, enlarged, Oneonta-Catskill of North America, Old Red Sandstone of Europe. (I. F.)

FIG. 1337. — *Stylonurus excelsior*, restoration of a specimen nearly five feet long.

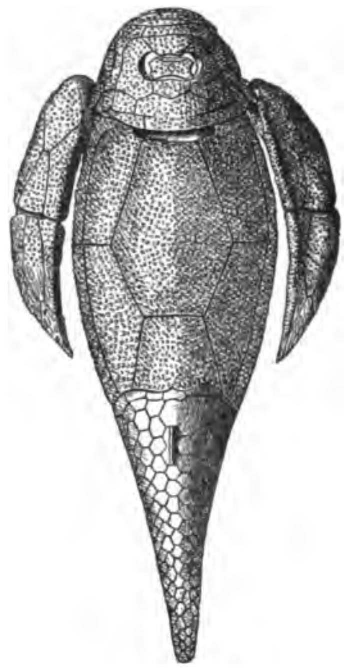


FIG. 1338. — An ostracoderm (*Pterichthys cornutus*). From the Old Red Sandstone of Scotland. (From Haas' *Leitfossilien.*)

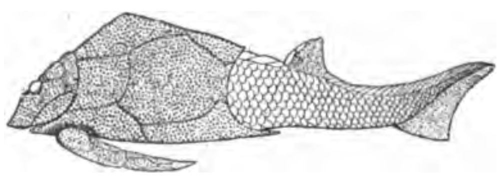


FIG. 1339. — *Pterichthys milleri*, an ostracoderm from the Old Red Sandstone. (After Kayser.)

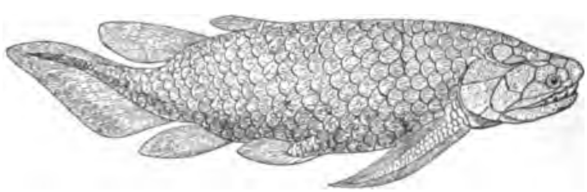


FIG. 1340. — *Holoptychius flemingi*, a ganoid fish from the Old Red Sandstone. (After Kayser.)

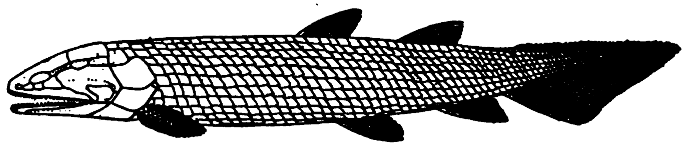


FIG. 1341. — Devonian ganoid, *Osteolepis macrolepidotus*. Lower Old Red Sandstone. Restoration after Pander.

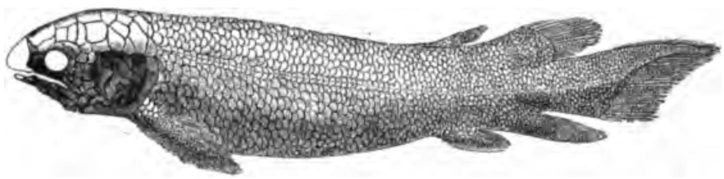


FIG. 1342. — Devonian lung fish (Dipnoan), *Dipterus valenciennesi*. Lower Old Red Sandstone, Orkney Islands. Restoration; ½ natural size.

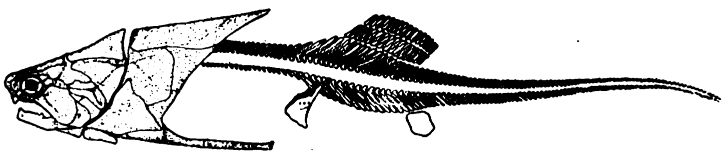


FIG. 1343. — Reconstruction of the skeleton of *Coccosteus decipiens*, less than ½ natural size. Lower Devonian, Old Red Sandstone, Scotland. (After Stromer.)

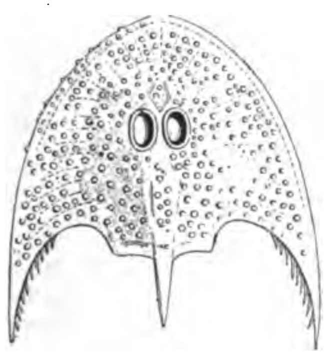


FIG. 1344. — Head-shield of *Cephalaspis lyelli*. Lower Old Red Sandstone, Scotland; ½ natural size.

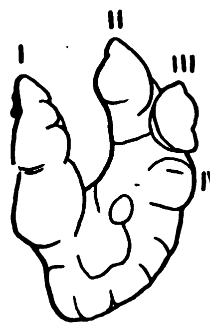


FIG. 1345. — Earliest known footprint (*Thinopus antiquus*), from the Upper Devonian of Pennsylvania. I–II, fully developed digits; III, budding third; IV, possible rudiment of fourth. (After Lull.)

(about 30 per cent), arthrodires and lung fish (about 40 per cent), and ostracoderms. (See also Chapter XC.)

The only indication of the existence at this time of higher forms of vertebrates than fish is found in a single foot-print of a primitive amphibian (*Thinopus antiquus*, Fig. 1345), which has been found in the Upper Devonian strata of

FIG. 1346. — *Psilophyton princeps*, a characteristic Devonian plant restored. (After Dawson.)

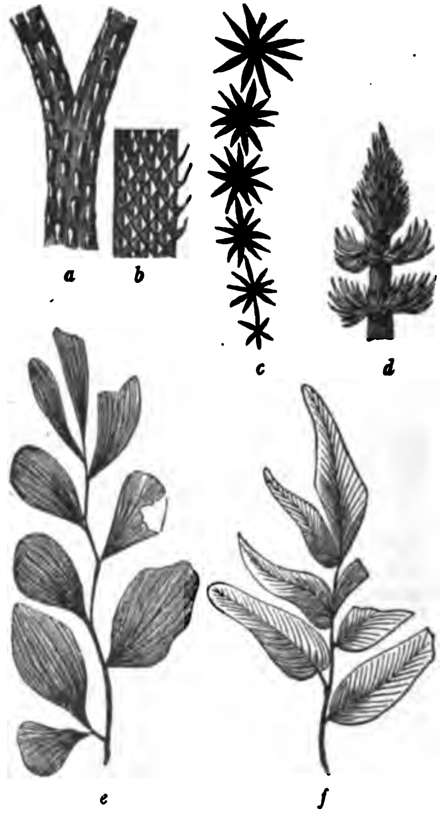


FIG. 1347. — Devonian Plants. *a–b*, *Lepidodendron gaspianum*, with enlargement; *c*, *Asterophyllites latifolia*; *d*, fruit of the same; *e*, *Cyclopteris obtusa* (fern); *f*, *Neuropteris polymorpha* (fern).

western Pennsylvania. This foot-print, which is about 4 inches long, is suggestive of the foot form of an immature salamander and represents an early type of amphibian with the foot structure still in a primitive stage of development.

In the later Devonian continental deposits we meet, for the first time, with well-preserved land **plants**; but these are already of such a high order of development that we must assume the existence of land plants at a much earlier time, probably throughout the Silurian if not before. The most characteristic Devonian plants are fern-like forms (Fig. 1347) and *Psilophyton* (Fig. 1346), in the Upper Devonian beds, the trunks and other remains of lycopods and ancient calamites (Fig. 1347 *a–d*), and of the early conifers (*Cordaites*). Spores of plants related to the modern water-ferns are often very abundant in the black shales and have been thought to be one of the chief sources of their carbonaceous matter. In some cases plant accumulations were so abundant as to produce thin coal seams. Such beds of bituminous coal, up to 3½ feet in thickness, are found in the continental Devonian rocks of Bear Island, north of Norway.

FIG. 1348. — Section of the Devonian strata at Eighteen Mile Creek, western New York. At the base of the section fossiliferous upper Hamilton (Windom) beds, covered by the projecting *Styliolina* (Genundewa) limestone, above which are the black lower Portage shales of the Upper Devonian. The thin Genundewa limestone carries fish and plant remains besides conodonts, especially in its lower portion (conodont layer). Plant remains are also found in the immediate overlying black shale (lower Portage).

CHAPTER XXXVI

THE MISSISSIPPIAN OR MISSISSIPPIC SYSTEM

In the days of William Smith the coal-bearing rocks of Great Britain were called the Coal-measure series, and they were known to be underlain in many sections by a great quartz-pebble conglomerate, which, because of its extended use for the manufacture of millstones, came to be designated as the Millstone Grit. Below this rock, or, in its absence, below the coal-bearing strata, was found either a series of shaly and sandy beds with some marine fossils but more generally with plant-remains, and designated the *Culm*, or a great series of limestones, to which the name Carboniferous Limestone was applied. In western Britain and in Ireland, where it often forms lofty ridges, it was also called the Mountain Limestone.

When, in 1822, the name Carboniferous was proposed by Conybear, these limestones and equivalent beds came to be classed as the *Lower Carboniferous division*, by which name they are still known in many European countries. In Belgium they are especially well developed and rich in organic remains, and these have been made known by the labors of the Belgian geologist, De Koninck, who gave to the world a series of elaborately illustrated monographs on these fossils which form the standard works of reference.

In North America these pre-Coal-measure strata have a varied development, as will be more fully shown presently, and to distinguish them as a group the name *Sub-Carboniferous* was proposed for them by Owen (1832). This name was later replaced by Mississippian (Winchell, 1870) because of the marked development of the strata in the Mississippi Valley. The extended study which these rocks have received from American geologists has shown the desirability of separating them as a distinct system

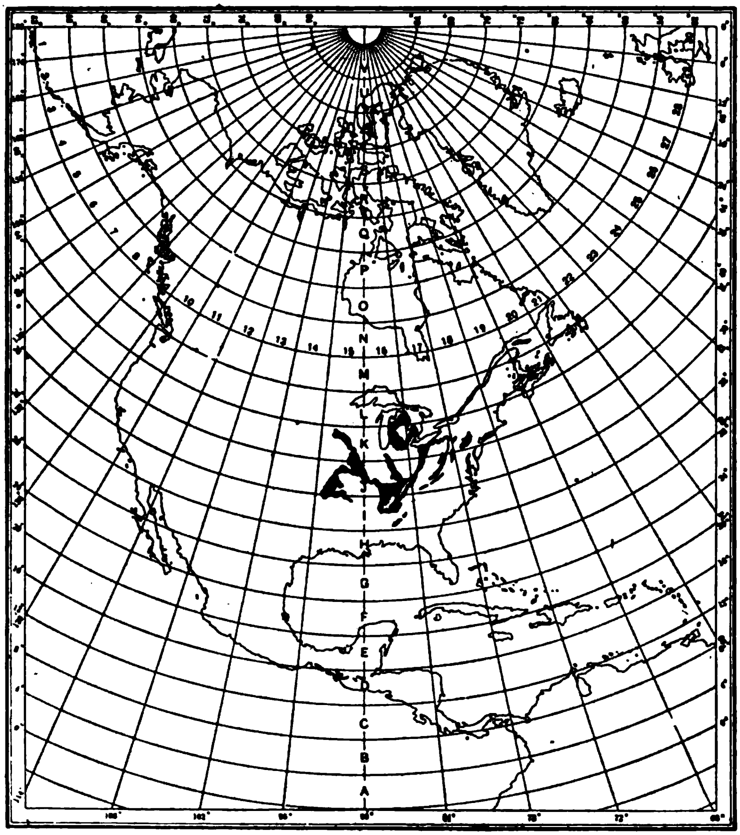


FIG. 1349. — Map showing the outcrops of the Mississippian rocks in North America. (After Bailey Willis.)

from the Coal-measure beds or Carboniferous proper, which have since become generally known by the name *Pennsylvanian* (H. S. Williams, 1891), though this name has not been adopted in Europe, where Upper and Lower Carboniferous continue to be largely used for these two systems.

The Mississippian of North America

Three typical sections may be given to show the variations of the character of the Mississippian deposits from the Mississippi Valley eastward.

Mississippi Valley	Ohio	Eastern Pennsylvania
Upper Mississippian or Chester Group. Kaskaskia series. St. Genevieve limestone.	*(Break in succession.)* Maxwell limestone.	Mauch Chunk red shales and sandstones with Greenbrier limestone in some sections.
Middle Mississippian or Meramec Group. St. Louis limestone. Spergen limestone. Warsaw beds. *(Break in succession.)*	*(Break in succession.)*	
Lower Mississippian or Osage-Kinderhook Group Keokuk limestone. Burlington limestones. Kinderhook beds.	Lower Mississippian or Waverly Group Logan sandstone. Cuyahoga shale and Black Hand sandstones and grits. Sunbury shales. Berea sandstone.	Pocono sandstone.

The Lower Mississippian

The closing stages of the Devonian period were marked by the expansion of the continental Catskill beds from Appalachia westward and the northward spread of the black muds by rivers from the south, where the low, flat country was covered with a layer of black, partly residual soil, comparable to the black earth or tchernosem of Russia. Overlying these black shales, we find in Ohio and Michigan gray shales and sandstones, often beautifully ripple-marked, and passing upwards into red shales which represent the extension of the red beds of the east. These beds, known as the *Bedford shales*, contain fossils at a few restricted levels and mark the final retreat of the sea from the interior, this retreat being apparently to the northwest. Then follows the *Berea sandstone*, a remarkable, more or less irregularly distributed sand, which is of importance in that it contains both brines and oil, but is, as a rule, devoid of marine fossils. It forms the base of the Mississippian of this region and between the Berea sandstone and the Bedford shales there is sometimes seen an erosion surface (Fig. 536, p. 615, Pt. I). Southward in Kentucky this Berea sandstone is laterally replaced by the black shale (*Chattanooga*), and an extension of this shale, the *Sunbury*, covers the Berea in turn. The relationship is shown in the following diagram (Fig. 1350).

The following seems to be a rational explanation of this section. In the closing stages of the Devonian the sea still lingered over Ohio, Michigan, and parts of Pennsylvania, and into it were washed the black muds which now form the Ohio shales. The southern shore of this sea lay near the Ohio-Kentucky line, and north of this the lowlands were covered by the black earth which supplied the muds from which the Ohio shales were formed. This black mud is now the Chattanooga black shale of these states, and it locally carries thin seams of coaly matter. But meanwhile the Catskill delta or alluvial fan was advancing from the east, and when deposition of the black muds had ceased, it covered them and so formed the Bedford shale. Then this region remained dry land for a while and over it accumulated the fine sands (probably

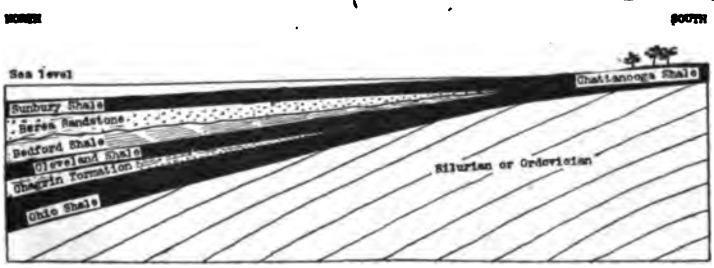


FIG. 1350. — Diagram showing the relation of the black shales to the other formations. The source of the black mud is the land on the south from which it was repeatedly washed into the sea, interfingering with clastics derived from the east. The Berea, Sunbury, and Chattanooga formations are Lower Mississippian, the others Upper Devonian. (Original.)

in large part wind-borne) which now form the Berea sandstone. Then the sea advanced again from the north southward, and the black muds were once more washed into it, and so the Sunbury shale with marine fossils was formed. From this relationship it is readily seen that the oil of the Berea is the distillation product of the organic matter in the black shales in the south, passing laterally into the porous sandstone and held in it by the capping layer of black shale.

At the opening of Mississippian time, then, we find an interior sea covering Ohio, Michigan, and the region westward beyond the present Mississippi Valley (Fig. 1351). This sea was transgressing southward over a region covered with black soil. Sometimes this black earth was reworked by the advancing sea, and became a black, fossiliferous basal bed. In other regions it remained practically undisturbed and the first of the marine beds was deposited upon it. Whenever the waters were pure, these beds

FIG. 1351. — Palæogeographic map of North America at the opening of Mississippian time. P. = Pocono alluvial fan. Seas in black. (Original.)

covering the black muds were limestones; but in the more easterly portions, where muds and sands were washed in by the rivers from Appalachia, the covering beds consist of terrigenous clastics.

A noteworthy fact is the presence in some of the basal black shales (base of Sweetland shales of Iowa) or in the beds immediately above them and in the basal beds of the Kinderhook (Missouri) of numerous fish teeth which appear to belong mostly to one species (*Ptyctodus calceolus*, Fig. 1389). If this fish was a river type, as seems not unlikely, its presence at this level seems to indicate the effect of the encroaching sea upon the river or estuarine fauna, which was abruptly exterminated. The presence of this form in Upper Devonian limestones of Iowa has, however, been taken as evidence that these fish were marine, though even in this case a secondary inclusion of the remains of river types may have taken place. At this time the sea appears to have been largely withdrawn from the central Appalachian trough, though a part of this trough in Virginia and eastern Tennessee continued to be occupied by an extension of the interior waters, and here the late Devonian and early Mississippian beds appear to form a continuous depositional series. The northern end of the trough in Nova Scotia, etc., was also occupied by the sea, and in it limestones and other deposits accumulated, but in the central region (Pennsylvania, etc.), heavy deposits of clastic material were accumulating in subaërial deltas or alluvial fans, the most pronounced of which, now represented by the *Pocono* sandstones, appears to have had its center of accumulation in the region of the Susquehanna, where, above Harrisburg, it is 2000 feet or more in thickness, and often consists of a quartz-pebble conglomerate. From this region it thins in all directions by overlap of the higher beds away from the source of supply, which was in Appalachia on the east.

Except in the marginal portions of the ancient alluvial fan the Pocono beds contain practically no other organic remains than land plants, these including many trees of the *Lepidodendron* type so abundant in the next period. On the flatter portions of the alluvial fan swamps were not uncommon, and in them vegetable material accumulated, which to-day is preserved in the oldest workable coal beds of America, though these are never of very great thickness. Where the beds entered the sea, however, around the margins of the spreading deposit, they included some of the characteristic remains of the marine organisms of the period. These have been found in Maryland, southwestern Virginia, West Virginia, and in southern Pennsylvania.

Similar deposits were forming at that time in the northern end of the Appalachian geosyncline, where they now constitute the *Horton* series of Nova Scotia, in which are sometimes found the basal parts of the ancient Lepidodendrons, still standing erect in the soil where they grew. These stumps were buried in an upright position by the deposits of fine sand and mud around them as trees are buried to-day by floods of Alaskan rivers.

The rivers which spread these sands and gravels as alluvial fans over the eastern region, carried the finer material westward into the interior sea, where it accumulated as the *Cuyahoga* marine

FIG. 1352. — Exposure of Keokuk limestone (Geode bed), capped by Warsaw shale along the banks of the Mississippi, Keokuk, Iowa.

shales of Ohio, and Michigan with their included sandstone beds, and the corresponding beds of Indiana. Farther west in parts of the sea not reached by these muds (Illinois, Iowa, Missouri regions), limestones accumulated, these being formed of the shells of brachiopods and the stems, plates, and other parts of crinoids which grew in great abundance in the shallow and probably warm interior seas (Fig. 1352). As the sea transgressed the successive divisions of the Lower Mississippian progressively overlapped one another in a general southward direction. Thus, while in Iowa the lower Kinderhook division rests directly upon eroded Devonian limestones, in east central Missouri the middle Kinderhook rests upon black shale which, in turn, lies disconformably upon Silurian or older strata. Again, in southwestern Missouri, upper Kinderhook beds lie upon the older rock, with a basal bed of black shale, and in northwest Arkansas the basal black shale is followed directly by beds of Burlington age. This is represented in the following diagram (Fig. 1353). In various parts of Tennessee, too, beds

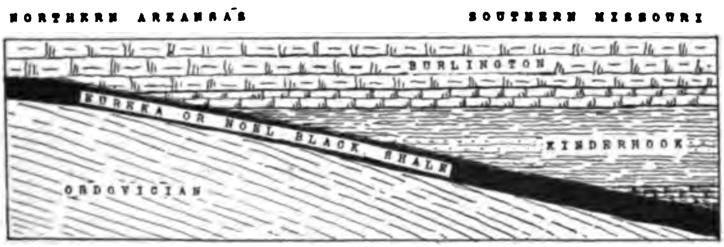


FIG. 1353. — Section showing the southward overlapping of the Lower Mississippian strata (Kinderhook and Burlington), with the black Noel (Eureka) shale forming a basal bed which rests with a hiatus upon the Ordovician. (Original.)

of Burlington, or even of Keokuk age, follow directly upon the basal black shale (Chattanooga), while in Kentucky beds of Kinderhook age generally appear as the first formation above the black shales.

The following east-west section (Fig. 1354) shows the general relationship of these various beds, the continental Pocono in the east, the Kinderhook beds and Burlington-Keokuk limestones in the west, and between them the Waverly group of Ohio, consisting of shales and sandstones (Berea, Sunbury, Cuyahoga, Logan) and the Knobstone of Indiana.

The southward overlap of the Lower Mississippian beds is found in all the exposures both east and west of the Mississippi Valley, and practically everywhere this overlap was upon the black soil now transformed into the Chattanooga shale, which in turn always rests upon the eroded and weathered surface of Silurian or Ordovician (more rarely Middle Devonian) rocks, and frequently encloses weathered-out fossils of the older rocks in its basal layers. In some sections the weathering of the older (Ordovician) rock has gone so far that extensive residual accumulations of the shells formerly scattered through these rocks were formed. In western Tennessee these shells (mostly the young pelagic stages of gastropods) were highly phosphatic, and this concentration has produced important beds of phosphate of lime at the base of the Chattanooga shale (Fig. 1113, p. 292). Such evidence of prolonged exposure to the weather, as well as the presence of the black earth itself — the ancient tchernosem which accumulated during a long period of time as

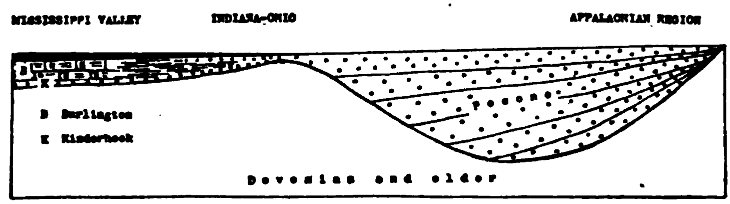


FIG. 1354. — Ideal section from Pennsylvania to the Mississippi Valley region, showing the relationship at the time of deposition of the Lower Mississippian strata. The Pocono beds on the east represent alluvial plain deposits in the Appalachian geosyncline. In the west, in the eastward transgressing sea, marine limestones and shales were forming with a basal sandstone of submergence. (Original.)

a more or less loess-like deposit, highly charged with decaying plant material — clearly indicates that all of this southern region was exposed land while the sea occupied the interior region farther north (Ohio, Michigan regions) and westward.

Only in the Mississippi Valley itself, in eastern Arkansas and western Tennessee, is the evidence of such overlap unrecognizable, because there all the older rocks are covered by Cretaceous and Tertiary deposits. It has sometimes been held that a connection of the interior sea with the ocean on the south might have existed along this now covered region, but this is very doubtful, because along the northern border of the covered area, as well as on each side of it, the overlapping relations are shown wherever the older beds are exposed to view. Hence we conclude that a continuous land mass bounded the Mississippian interior sea on the south, as it bounded the Devonian sea, and that no direct connection existed with the waters of the southern (Pacific) sea as was the case during the Silurian and Ordovician. Nor was there any connection with the Atlantic, for Appalachia remained throughout this period, as before, a continuous land mass, this being clearly shown by the character of the sediments and by their overlaps.

This leaves only the northwest as the pathway of communication between this interior sea and other open waters, for that some connection with oceanic waters existed can hardly be questioned. Indeed the connection with the sea which occupied the Cordilleran trough at that time is indicated by the character of the fauna of some of these beds, notably the later Kinderhook (Chouteau fauna), and this connection was across northern Missouri and perhaps southern Iowa, while an arm of the interior sea seems to have extended at least as far to the southwest as New Mexico. (See Fig. 1351, p. 442.)

It is recognized that a part of the Kinderhook fauna (southern region) was derived by modification from the Hamilton fauna, while another part (northern region) was derived from the Chemung fauna. The Hamilton fauna had its seat of development in the Atlantic Ocean, hence a return of the Hamilton fauna, though in modified form, at the opening of the Mississippian would imply reëstablishment of a connection between the Atlantic Ocean and the interior waters. But, as we have seen, this connection could hardly have been on the south, where the various members are everywhere seen to overlap against a land mass, unless it was by way of the Mississippi Valley. This connection may have been in the north, along a path from which the profound post-Palæozoic erosion has removed every trace of these deposits.

Nevertheless, it must be noted that the known deposits in the northern end of the Appalachian trough, *i.e.* in the Acadian area, are muds, sandstones, and conglomerates, much of them probably of continental origin although gypsum and limestone beds occur. These limestones often consist wholly of marine shells, mainly of species unknown elsewhere either in America or Europe. There is, however, another interpretation which seems more in accord with the character and distribution of the sediments, and that is that the Chouteau fauna, or that part of the Kinderhook fauna which shows Hamilton affinities, is of western origin. For it must be remembered that there was also a western or Asiatic Hamilton (Traverse) fauna which, though related to the eastern fauna and partly derived from it, was, nevertheless, distinct and, moreover, persisted into the Upper Devonian. From this the Mississippian fauna of the west may have been derived, the mother fauna repeatedly sending immigrants into the interior, where they soon underwent profound modification. The whole problem is very complex and requires much more study than it has received so far. That portion of the Kinderhook fauna which was derived from the Chemung fauna seems to indicate a northward sea connection.

The rich crinoid fauna of the Burlington and Keokuk beds appears to be largely the product of rapid evolution in the interior

FIG. 1355. — View of outcrop of Madison limestone, near Chestnut, Mont. Looking east. (U. S. G. S.)

Lower Mississippian sea. It is unknown in the deposits of the Cordilleran trough and, for that matter, anywhere else. This would indicate that the interior sea was more or less an isolated province, though of course some connection with oceanic waters must have existed, else evidence of stagnant conditions could hardly be lacking. Such a connection is indeed indicated by the fact that the other fossils, especially the brachiopods, are closely allied to, if not identical with, the species of the Mountain Limestone of Ireland, England, and other European countries. They appear to have originated in the interior American waters and migrated to Europe, but the path of migration is still unknown. It may have been across the Arctic, though there are vast areas from which these strata are absent, or it may have been by a northwest passage across Asia.

In the Cordilleran trough and its eastward extension into the region which was later on raised into the Rocky Mountains, great limestone masses (*Madison limestone*, etc. Figs. 1355, 1356) accumulated during Lower Mississippian time, and these limestones appear to succeed conformably the Upper Devonian limestones of that region, so that these beds are sometimes known by a single name (*e.g.*, *Ouray limestone* of Colorado), though the lower part is Devonian and the higher Mississippian.

Too little is still known of the faunas and sediments of the main Cordilleran basin, but the thickness of the formations there far exceeds that of the widespreading beds of the interior. Some of

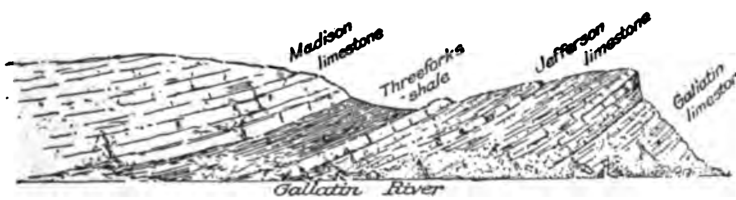


Fig. 1356. — Section on the Gallatin River near Logan, Mont., showing the Madison limestone (Mississippian) resting with apparent conformity upon Devonian (Three Forks shale and Jefferson limestone), which in turn rests disconformably upon the Cambro-Ordovician Gallatin limestone. (U. S. G. S.)

these dolomites appear to grade upward into the later Mississippian beds, and their organisms repeatedly entered into the central region.

The Middle Mississippian

The top of the Lower Mississippian or Waverlyan series is marked everywhere in the interior by an erosion surface which separates it from the next succeeding series. This indicates that the sea again withdrew and the land rose. The withdrawal was either northward or northwestward or both, and the elevation of the country is further indicated by the extensive development of continental sediments. Such deposits appear to have formed in central Arkansas in an east-west trough, which lay at the foot of a highland on the south from which the sediments were derived. In the central Appalachian trough oxidized sands and mud were deposited, these being now of a red color, and forming the lower

Mauch Chunk series. Their color contrast with the gray Pocono beds indicates a change towards aridity of climate. These red beds extend west to Michigan, where they cover the fossiliferous sandstones which terminate the Lower Mississippian series (lower *Marshall sandstone*). In Michigan these red beds contain disseminated salt crystals, and this further emphasizes the climatic change. The beds were essentially a salt clay, probably formed along the margin of the retreating sea, and they were covered by sands, partly of eolian origin, forming the *Napoleon sandstone* which is to-day heavily charged with brines from those old salt beds.

Exposure to a relatively dry climate would effect the destruction of the limestones of the previously deposited series more by disintegration than by solution, so that lime-sand should be formed over the exposed surface. If such lime-sand were subjected to wind activity, all the finer material would be heaped up into dunes and an eolian structure impressed upon it. If now we find that in many places the first limestone above the erosion plane consists of fine lime-sand with much eolian structure, we may safely conclude that it is the product of the partial rearrangement of the residual lime-sand by the readvancing sea without complete destruction of the eolian structure.

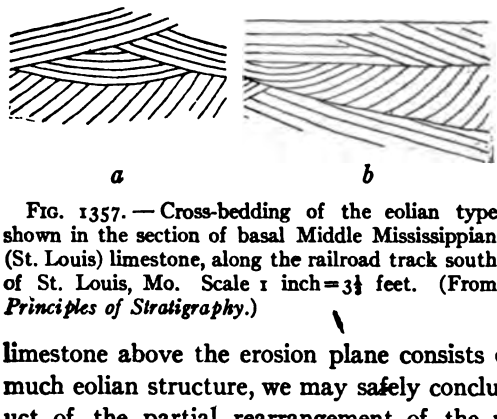


FIG. 1357. — Cross-bedding of the eolian type shown in the section of basal Middle Mississippian (St. Louis) limestone, along the railroad track south of St. Louis, Mo. Scale 1 inch = 3½ feet. (From *Principles of Stratigraphy*.)

Such is the character of the Salem or Spergen limestone in some sections where it follows upon the erosion surface (Fig. 1357), while elsewhere it is an oölite, and was deposited as are modern oölites, either in salt lagoons or in arms of the readvancing sea. That this readvance was from the northwest is indicated by the fact that the fauna of the Salem limestone is also found in Mississippian limestones in Idaho and northwest Montana. Still another marginal deposit of the readvancing sea was gypsum, of which a considerable thickness characterizes the Middle Mississippian beds in Michigan, while gypsum and rock salt, associated with fossilif-

FIG. 1358. — Palæogeographic map of North America in meso-Mississippian (St. Louis) time, showing the distribution of land and sea (black). (Original.)

erous beds, formed probably in marginal lagoons, characterize the deposits of the readvancing sea in Virginia (Saltville region). The geography of this epoch is shown in the map at the top of this page (Fig. 1358).

As transgression of the sea continued, the waters of the interior again became normal marine waters, and a pure limestone, the *St. Louis*, with corals (*Lithostrotion*, Fig. 1372) and large melon-like sea-urchins (*Melonites*, Fig. 1388 *i*), was formed. Along the shores muds were still deposited, examples of these being the *Moorefield shales* of Arkansas and the *McGrady* formation above the salt beds in Virginia.

The Upper Mississippian

The transgression of the sea did not extend over Ohio and Pennsylvania in St. Louis time, but these regions were submerged during the continuance of the transgression in St. Genevieve time,

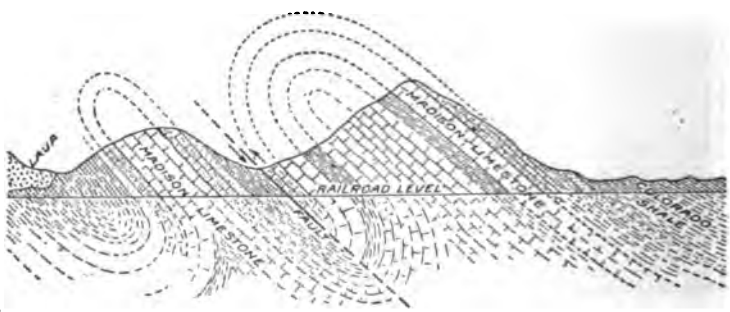


FIG. 1358 *b*. — Section near Livingston, Mont., showing isoclinal folds and faulting, with repetition of the outcrops of Madison limestone (Mississippian). S. E. on left. (U. S. G. S.)

when the beds of that name were deposited in the Mississippi Valley. In Ohio these beds (known as the *Maxville limestone*) lie disconformably upon the eroded surface of the Waverly group,

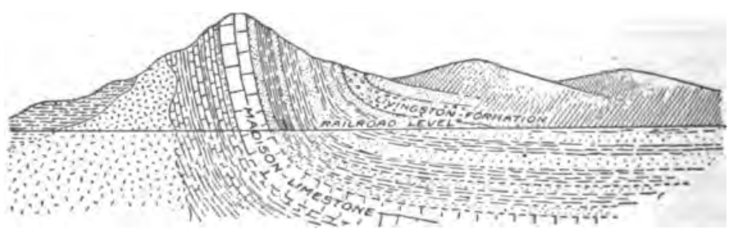


FIG. 1358 *c*. — Section of the Bridger Range, Mont., showing the upturned Madison limestone and associated rocks in a uniclinal fold, resting against the crystallines on the left. (U. S. G. S.)

and in southern Pennsylvania and Maryland (where they are known as *Greenbrier limestone*), they lie upon the red beds of the lower Mauch Chunk. In the southern Virginia region of the geosyncline limestone continued to be deposited until over 3300 feet had accumulated (*Newman limestone*); but both to the north of this region in Pennsylvania and to the south of it in eastern Tennessee, terrigenous deposits again became characteristic after the first period of invasion. In Pennsylvania these terrigenous deposits continued to be oxidized sands and muds (upper Mauch Chunk red shales), while in eastern Tennessee and in Alabama deltas were being built from Appalachia into the sea, as is shown by the fact that continental sands and clays in the more easterly and southerly region grade laterally into marine clays and limestone beds, and are interfingered with them in more westerly and northerly regions. Still farther from the shore, limestone (*Bangor limestone*, etc.) takes the place of the marine shales. One of these deltas is shown in Fig. 1359. The Price sandstone belongs to the Lower Mississippian, the remaining formations to the Middle and Upper Mississippian. The "Greenbrier" limestone of this southern section is not the exact equivalent of the formation of the same name in Pennsylvania.

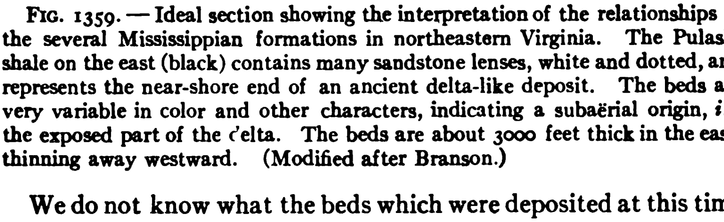


FIG. 1359. — Ideal section showing the interpretation of the relationships of the several Mississippian formations in northeastern Virginia. The Pulaski shale on the east (black) contains many sandstone lenses, white and dotted, and represents the near-shore end of an ancient delta-like deposit. The beds are very variable in color and other characters, indicating a subaërial origin, *i.e.* the exposed part of the delta. The beds are about 3000 feet thick in the east, thinning away westward. (Modified after Branson.)

We do not know what the beds which were deposited at this time in the northern Mississippi Valley region were like, because they were eroded again before the deposition of the Coal-measure strata. But in the southern Mississippi Valley (southern Illinois, etc.) they were shales, sandstones, and thin limestones, with the calcareous beds predominating in some sections (Tennessee, northern

Alabama), but generally passing laterally (eastward and southward) into shales. This is illustrated by comparing two sections:

A. MURPHREES AND NORTHERN PART OF BIRMINGHAM VALLEY, ALABAMA			*B.* SOUTHERN PART OF BIRMINGHAM AND SHADE VALLEYS, ALABAMA
FORMATION	THICKNESS IN FEET		FORMATION
Parkwood formation Gray shales and sandstones, no calcareous beds — fossils very rare.	2000	2000	*Parkwood formation* Same character.
Pennington shale Gray, green, and red shales with some chert, sandstone, conglomerate. Very fossiliferous.	60 to 300	1000	*Floyd shale* Gray, dark, and black shales, calcareous at certain levels. Beds of sandstone and lenses of limestone occur. Generally fossiliferous.
Bangor limestone Highly fossiliferous limestone, thick bedded, with a 100-foot shale and sandstone member in the middle.	700		
Fort Payne chert Thin-bedded cherty limestone and chert.	200	200	*Fort Payne chert* Same as farther north.
Chattanooga black shale			*Chattanooga black shale*

In Arkansas and Oklahoma the highest Mississippian beds are dark, often bituminous shales, a thousand feet thick (*Caney*

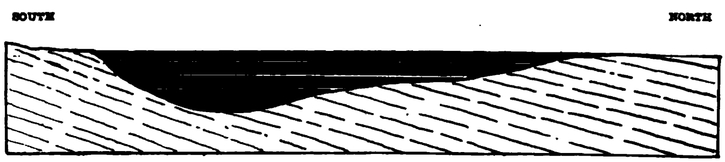


FIG. 1360. — Ideal section showing the character and relationships of the Mississippian beds of the Quachita Geosyncline in the southern United States. (See section Fig. 1003, p. 213.) (Original.)

shales), which apparently represent the wash of the muds from the subdued upland which then lay to the south and part of which is now submerged beneath the younger coastal plain strata (Fig. 1360).

Because of the essential unity of the series from the Salem or Spergen limestone (or the Warsaw shales, when present) to the top of the Mississippian, representing as they do, on the whole, continuous transgression with some minor retreats of the sea, they have recently been classed together as the Tennesseean series, while the lower division is called the Waverlyan series. It may eventually be found that the period of emergence which separates

FIG. 1361. — Carboniferous Limestone (Mississippian) resting unconformably on Ludlow (Upper Silurian) slates, near Settle, Yorkshire, England. (After Lake and Rastall.)

these two series was of sufficient length to represent most of the middle division of the Mississippian. That it was long enough to permit a great change in faunas is clearly shown by the difference in the organic remains of the Waverlyan and Tennesseean. In general, then, the Mississippian beds of North America indicate a transgression of the sea followed by withdrawal, and a period of emergence of unknown length. This is followed by a second transgression and closed by an advance of terrigenous and even continental sediments with accompanying partial emergence.

The Mississippian or Lower Carboniferous of Europe and Asia

One of the characteristic features of the later Palæozoic of western Europe is the presence of extensive areas of great limestone deposits of Mississippian age, the so-called Carboniferous Limestone, or Mountain Limestone series, of the European geologists. These limestones are well developed in Ireland and in northern England, where they sometimes lie directly and unconformably upon the folded and eroded older Palæozoic rocks, and by their resistant character form great limestone cliffs or scarps (Figs. 1361, 1362). Such is the mountainous face of the Pennine escarpment of northwest England which rises above the beautiful Vale of Eden. A section of this is shown in Fig. 1363, where the unconformable relation at the base is seen and the succeeding beds, with the great intruded Whin Sill, appear near the top. In the west and southwest of Ireland the thickness of the Mountain Limestone reaches a maximum of 3600 feet. In northern France and Belgium, too, these limestones are well developed, and their organic remains have become well known through the labors of the Belgian palæontologists.

Fig. 1362. — Natural arch in Carboniferous Limestone, Manorbier, Pembroke, England. (British Geol. Surv. photo. From Lake and Rastall.)

Following as they do upon the Old Red Sandstone (Fig. 1364), a continental formation, or, in the absence of that rock, resting upon the eroded surfaces of older formations, it is evident that these limestones indicate a profound transgression of the sea at the opening of Mississippian time, the transgression being, in general, from the east westward. In a few localities, however, as in Belgium and in the north of France, this "Calcaire carbonifère," as it is called, and which in the region of the Meuse has a thickness of 760 meters, rests upon and passes downward into marine Devonian strata, showing that the sea covered this region continuously from Devonian into Mississippian time. Overlying these limestones lie

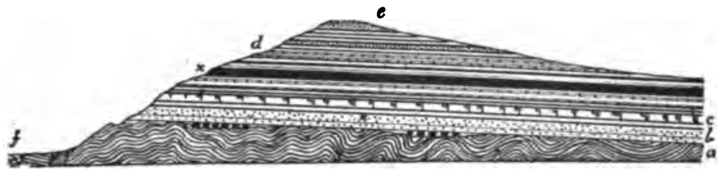


FIG. 1363. — Section of the Cross Fell in northwestern England, to show the relationship of the Mississippian strata (Carboniferous Limestone) to the older and younger beds. *a*, Silurian and Ordovician; *b*, Flags and Sandstones, Quartz conglomerates, Basement conglomerates, the last in hollows in the floor of older rock; *c*, Melmerby Scar Limestone; *d*, Yoredale Series (shales, sandstones, limestones); *e*, Millstone Grit (Upper Carboniferous); *f*, Trias; *x*, Whin Sill (intrusive). (After Lake and Rastall.)

shales and sandstones with coal seams, indicating a return toward continental conditions after the first great advance of the sea.

These great limestone deposits probably represent the greater part, if not the whole, of Mississippian time, though it is not improbable that a break may yet be found near the middle of the series indicating a partial retreat and readvance of the sea as was the case in North America.

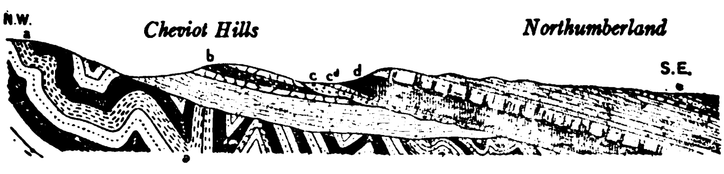


FIG. 1364. — General section of the Cheviot Hills in the west of Northumberland, England. (After J. G. Goodchild.) *a*. Silurian; *b*, Lower Old Red Sandstone; *c*, Upper Old Red Sandstone; c^d, intrusive sheet; *d*, *e*, Mississippian: *d*, lower Dinantian; *e*, upper Dinantian. (For subdivisions of Mississippian see table on p. 460.)

That this sea, in which the Carboniferous limestones were accumulating, was limited in extent is shown by the fact that both northward and southward these deposits grade into shore, shallow water, and even continental sediments. Thus in Scotland the deposits of this time were water-limes, that is, fine clastic lime sediments with a considerable proportion of alumina and some silica, so that the rock in places is known as the Calciferous Sandstone.[1] Such rock, we believe, is chiefly formed from fine river sediments, which were derived from the erosion of older calcareous beds within the drainage area of these rivers, the land being sufficiently near to base-level to furnish only very fine muds. It is recognized that this limestone is in part, at least, a fresh-water deposit; but it is succeeded by other limestones, some of which are marine, but among which important coal-seams are also found. These seams indicate repeated terrestrial conditions. The higher limestones of Scotland represent only the upper part of the Carboniferous Limestone series of England, for the lower part of that formation is represented in Scotland by the Calciferous Sandstone series.

One of the marked features of these deposits in Scotland is the great number of volcanic eruptions associated with them (Fig. 1365).

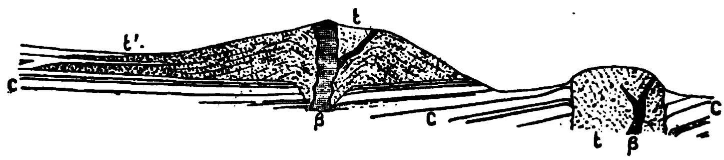


FIG. 1365. — Cross section of the volcano of the Saline Hills, Fife, Scotland. (After A. Geikie.) *C*, Carbonic; *β*, basalt; *t*, ejectamenta; *t'*, ejectamenta at a distance from the cone, interstratified with the Carbonic deposits. (From Haug.)

These eruptions began at the end of Old Red Sandstone time and ceased before the deposition of the Coal-measures. At first, while the Calciferous sand-rock was being formed, great masses, chiefly of andesitic lava, welled up quietly and spread as huge sheets over the surface, and from these lava caps erosion has subsequently carved plateaus. During the later part of the Mississippian period, basic lavas were erupted and volcanoes of the Puy type were formed (p. 165, Pt. I), many of them of fragmental (pyroclastic) material. The lavas as now seen in the coast sections often rest upon limestone beds which contain marine fossils. They are succeeded by ancient soil beds and sands in which the root-stocks (*Stigmaria*) of the old lycopodiaceous trees are preserved. Then follow one or several seams of coal; above these lie brackish-

[1] This must not be confounded with the old "Calciferous Sandstone" of America, which is of Ordovician (Beekmantown) age. The name is a lithologic one, and has no real stratigraphic meaning, although it has also been used as a stratigraphic term.

water, and later marine, fossiliferous shales, and finally limestones. They are again succeeded by a basaltic lava and the series is once more repeated.

These volcanic manifestations extended into northern England, as shown by the occurrence of many dikes and, above all, by the

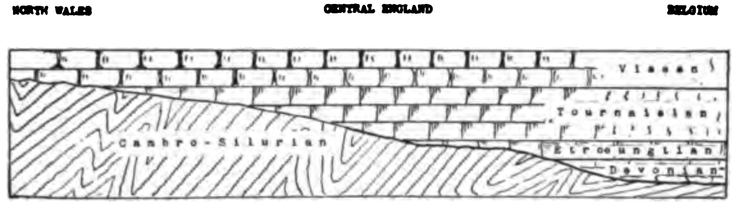


FIG. 1366. — Ideal section showing the relationships, lateral changes in character and overlaps of the Mississippian strata of Britain. (Original.)

great Whin Sill which is intruded in the upper shales and sandstones of the series (*Yoredale* beds). In Ireland, which is largely covered by Lower Carboniferous (Mississippian) rocks, volcanic activity is limited to a few regions (Limerick, etc.).

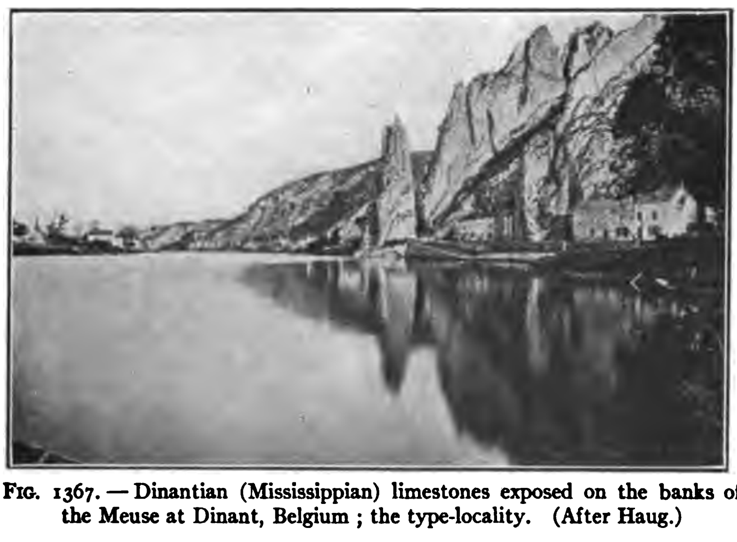


FIG. 1367. — Dinantian (Mississippian) limestones exposed on the banks of the Meuse at Dinant, Belgium ; the type-locality. (After Haug.)

The English Mountain Limestone admits generally of a fivefold division, each member being characterized by corals or brachiopods which are restricted to it and by the presence of which it can be recognized again in other localities. In some sections, as in

North Wales, the fifth and a part of the fourth zone from the bottom are alone present, resting on the older rocks. This shows that during the deposition of the earlier divisions or zones of the Mississippian series, those regions were dry land, and that the higher divisions overlap the lower. Hence a transgression of the Mississippian (Carboniferous Limestone) sea is indicated (Fig. 1366). In Belgium the limestones are well shown in the picturesque cliffs which border the Meuse at Dinant, and from this occurrence the entire system has become known as the *Dinantian* (Fig. 1367). Here it admits of the following threefold subdivision.

3. *Upper Dinantian* or *Visé division* (Viséan). (Includes the two upper English zones.)	Zone of *Productus giganteus* (Fig. 1368 *a*), and *Chonetes papilionacea*.
2. *Middle Dinantian* or *Tournai division* (Tournaisian). (Includes lower three English zones.)	Zone of *Spirifer tornacensis* (Fig. 1369 *a*).
1. *Lower Dinantian* or *Etrœungt division* (Etrœungtian). Conformable succession, Devonian limestones, etc.	Zone of *Phillipsia, Prolecanites* and *Spirifer distans*, etc.

These formations are folded and faulted and have suffered much erosion.

In central France the lower divisions are absent but the higher with *Productus giganteus* overlap them, extending as far south as Montpelier. This, therefore, shows a transgressing sea.

(¹/₄)

FIG. 1368 *a*. — *Productus giganteus*, one fourth natural size. Dinantian (Mississippian). (Kayser.)

From Belgium and northern France the Mississippian series is traced into central and southern Russia, into the eastern Alps and into the Ural Mountains. In most cases the series begins with marine deposits, then follow continental beds with coal, and finally marine beds succeed again. Interpreted, this means an advance of the sea, followed by a retreat, a period of exposure and continental sedi-

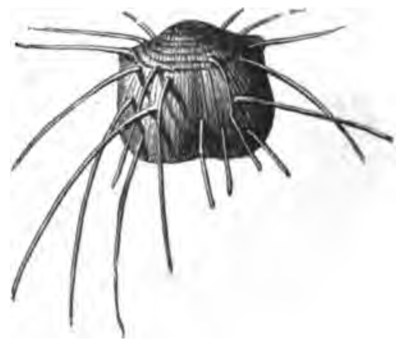


FIG. 1368 *b.*—*Productus longispinus*, Dinantian (Mississippian).

mentation, and the formation of coal swamps, and then by a period of renewed transgression. Thus the conditions were similar to those of North America where, however, the period of retreat was followed by erosion instead of the accumulation of vegetable material, as in Europe.

The shore facies in northern Europe is mostly a series of sandstones, conglomerates, and shales with plant remains, alternating with beds containing shallow-water marine faunas, and thus indicating backward and forward movement of the seashore. Such deposits are generally designated by the name *Culm*. A remarkable occurrence in this series is seen in beds rich in Radiolaria, which are suggestive of a deep-water origin for the formations, whereas the character and mode of occurrence of the other fossils, especially the plants, indicate shallow water. These radiolarian beds have therefore been interpreted as formed in lagoons from the pelagic organisms swept in by the currents, and from others which lived there. The upper division of the Culm beds is characterized by the widespread occurrence of the flat pelecypod shell *Posidonia becheri* (Fig. 1370).

FIG. 1369 *a.*—*Spirifer tornacensis*, Dinantian (Mississippian). (Kayser.)

The Culm type is found far to the north in Spitzbergen. Throughout southern Europe, on the other hand, the Mississippian is represented by limestones with fossils similar to those of western Europe, especially the very characteristic brachiopod *Productus giganteus* (Fig. 1368 *a*). These beds can be

FIG. 1369 *b.*—*Spirifer striatus*, a Dinantian (Mississippian) brachiopod with shell partly broken to show internal spiral arm supports.

traced south to Sarajevo in the Balkans, and through Asia Minor, Persia, and the Kirgiz steppe, through central Asia north of the Tian-Shan Mountains, through North China, and so on into the western part of the Cordilleran trough of North America, where the same *Productus giganteus* is found. These deposits, too, contain, locally, beds of workable coal, such an occurrence being especially known from the province of Shantung in China. The old Siberian basin, in which the early Palæozoic strata were deposited, remained a land mass; the sea, in which the younger Palæozoic beds were deposited, extended to the south of the mountains which bounded that basin.

(½)

FIG. 1370. — *Posidonia becheri*. A characteristic Culm (Mississippian) pelecypod of Europe. One-half natural size. (Kayser.)

SOUTHERN CONTINENTS

Very little is as yet known of the Mississippian of the southern continents. Limestones of this period have been described from Chile (32° S. lat.), while east of this, in Argentine, coal-bearing sandstones with the Culm flora have been found. This seems to indicate the existence of the Andean geosyncline along the Pacific coast. Such Culm deposits also occur in Queensland, New South Wales, and in Victoria in Australia, and apparently also in South Africa.

Summary

In general, then, we find that a transgression of the sea marked the opening of Mississippian time in Europe, as in America (Etrœungt stage). Then followed a retreat over wide areas, but not everywhere, when sands, clays, and coal-beds were deposited in Europe (Tournai stage), while erosion was going on in North America. Then came the most extensive advance of the sea in Upper Mississippian time (Visé stage), when the waters covered many regions not submerged before and extended as a continuous Mediterranean Sea across southern Europe, central Asia, North China, and into western North

FIG. 1371. — *Endothyra baileyi*, a Mississippian foraminifer, much enlarged. Indiana. (I. F.)

America, so that the characteristic *Productus gigànteus* fauna could become of almost world-wide distribution.

General Character of the Mississippian Fauna and Flora

Animals. — The American Mississippian still carries Devonian elements in both the lower and middle divisions, whereas in Europe the Devonian elements are most marked in the lower division.

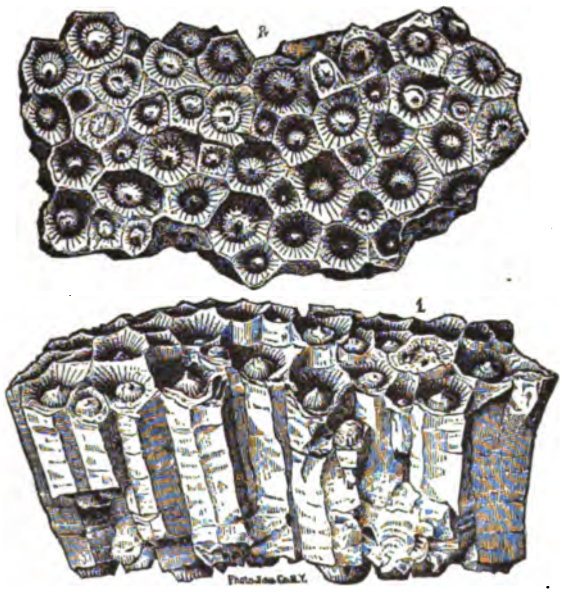


Fig. 1372. — *Lithostrotion canadense* (*mammillare*), St. Louis limestone. (From Grabau and Shimer, *North American Index Fossils*.)

Fig. 1373. — *Lithostrotion basaltiforme*. Carboniferous limestone (Mississippian) of Europe. (Kayser.)

Fig. 1374. — *Michelinia favosa*. Carboniferous limestone (Mississippian.) (Kayser.)

FIG. 1375. — *Archimedes wortheni* Mississippian (Warsaw division).

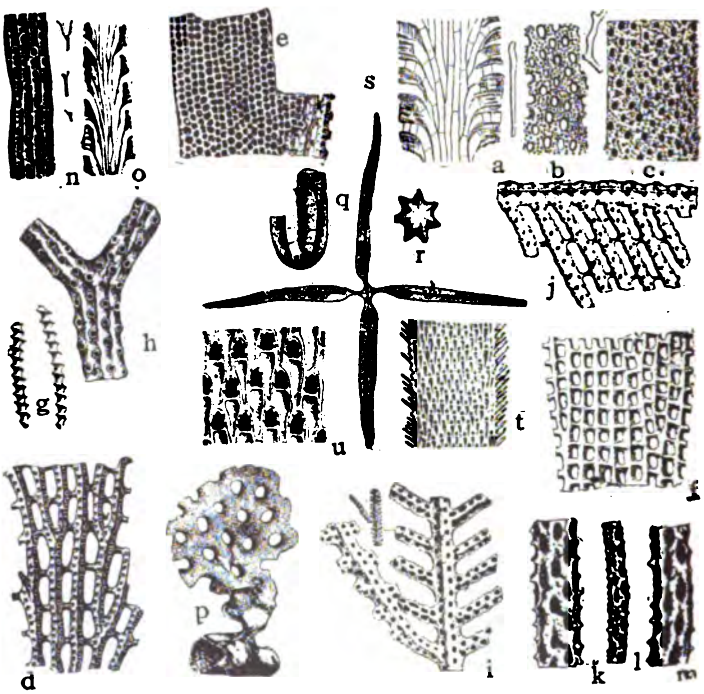


FIG. 1376. — Mississippian Bryozoa. *a–c*, *Batostomella spinulosa*, × ½, and vertical and tangential sections, and surface, greatly enlarged; *d*, *Fenestella cestriensis*, celluliferous face, ×4½; *e*, *f*, *Hemitrypa proutana*, opposite sides of frond, × 4½ (Keokuk, Warsaw, and St. Louis); *g*, *Archimedes communis*, × ½; *h*, *Thamniscus furcillatus*, ×9; *i*, *Pinnatopora conferta*, ×4½; *j*, *Ptilopora cylindracea*, ×4½; *k–m*, *Rhombopora tenuirama*, ×6, and ×12 (*k*, *m*,); *n*, *o*, *Streblotrypa nicklesi*, surface and section, ×9; *p*, *Coscinium latum*, ×½; *q*, *r*, *Evactinopora radiata*, lateral and basal views, ×½; *s*, *E. grandis*, ×½; *t*, *u*, *Worthenopora spinosa*, fragment showing spines, ×4½, and portion of same ×14. Chester species, *a–c*, *d*, *g*, *h*, *k–m*, *n*, *o*; Burlington species, *p*, *s*; Keokuk species, *i*, *j*, *q*, *r*, *t*, *u*. (All from I. F.)

Protozoa are represented by a few large types, some of which are important rock-formers (*Endothyra*, Fig. 1371). **Graptolites** are absent and **stromatoporas**, while occurring and even forming reefs, as in Belgium, are on the whole

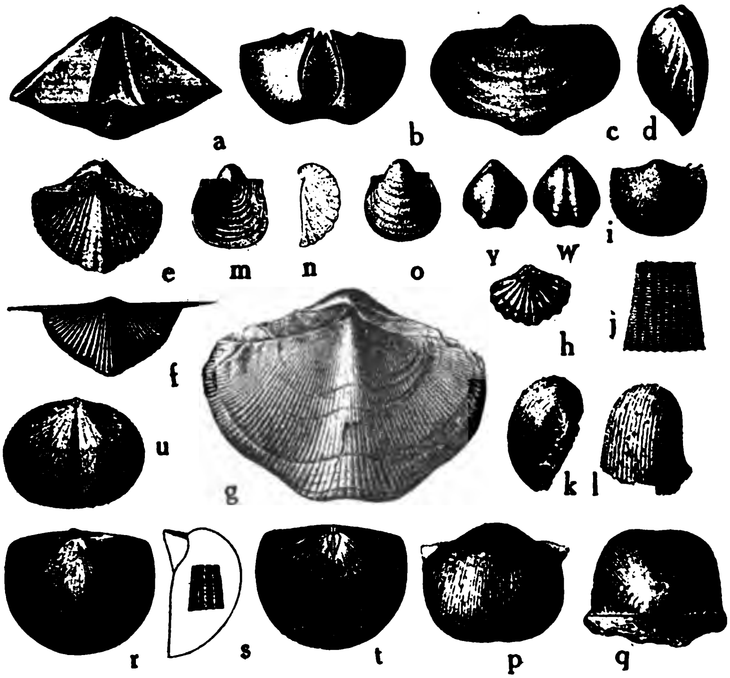


FIG. 1377. — Mississippian brachiopods. *a*, *Syringothyris texta*, cardinal view; *b*, internal mold (W.); *c–d*, *Athyris lamellosa* (W.); *e*, *Spirifer keokuk* (W.); *f*, *S. centronatus* (W.); *g*, *S. logani* (W.); *h*, *S. leidyi* (St. L.); *i–j*, *Chonetes aurora* with enlargement of surface (W.); *k–l*, *Productella arcuata* (W.); *m–o*, *Productus biseriatus* (W.); *p–q*, *Productus burlingtonensis* (W.); *r–t*, *Schuchertella crenistria* with enlargement of surface (in outline) (W.); *u*, *Rhipidomella michelini* (W.); *v–w*, *Seminula trinucleus* (St. L.). (W = Waverlyan; St. L. = St. Louis.)

on the decline. **Corals**, too, are no longer so marked an element of the fauna, though zaphrentoid types still occur (*Caninia*, *Hapsiphyllum*, etc.). The compound corals are now chiefly represented by *Lithostrotion* (Figs. 1372, 1373), characterized by a median columella-like projection in each calyx. *Favosites*

FIG. 1378. — *Dielasma turgidum*, a widespread, Middle Mississippian (Warsaw and St. Louis) brachiopod.

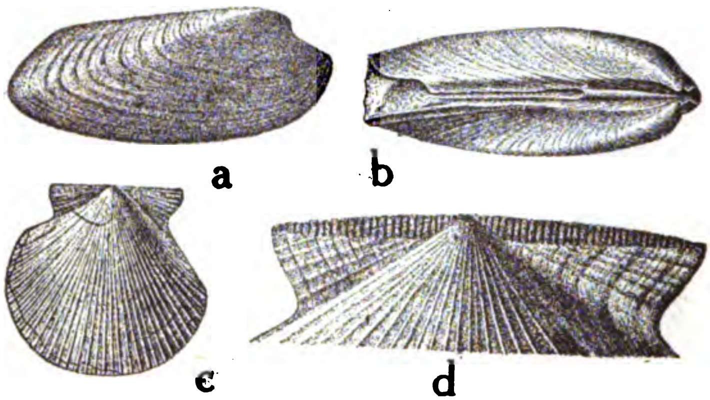


FIG. 1379. — Mississippian pelecypods. *a–b*, *Sphenotus æolus*, right valve and dorsal view (Waverly); *c–d*, *Crenipecten winchelli*, left valve and upper portion enlarged (Waverly).

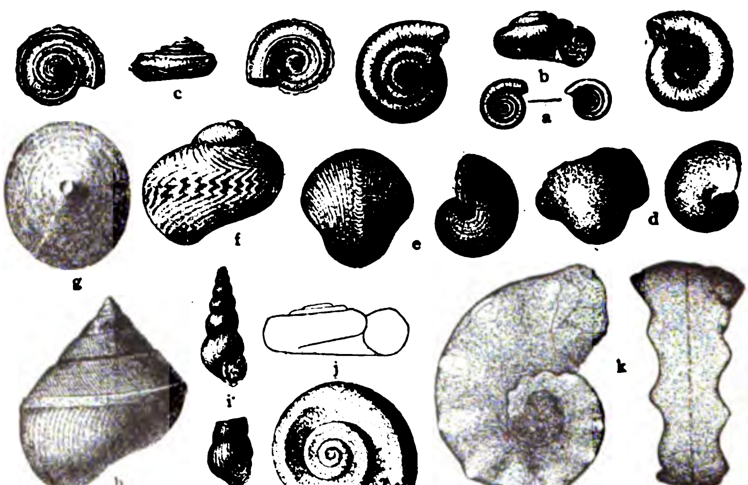


FIG. 1380. — Mississippian gastropods. *a*, *Straparollus planispira*, 2 views (St. L.); *b*, *Straparollus spergenensis*, 3 views (St. L.); *c*, *Euomphalus similis*, 3 views (St. L.); *d*, *Bellerophon sublævis*, 2 views (St. L. and Ch.); *e*, *B.* (*Bucanopsis*) *textilis*, 2 views (St. L.); *f*, *Naticopsis ziczac* (Ch.); *g*, *Lepetopsis levettei* (St. L.); *h*, *Pleurotomaria* (*Mourlonia*) *mississippiensis* (W.); *i*, *Loxonema yandellana*, 2 views (St. L.); *j*, *Euomphalus planidorsatus*, 2 views (Ch.); *k*, *Porcellia crassinoda*, 2 views (×½) (W.). (W. = Waverlyan, St. L. = St. Louis, Ch. = Chester.)

FIG. 1381. — *Endolobus spectabilis*, a characteristic Mississippian nautiloid. (Chester group.) (I. F.).

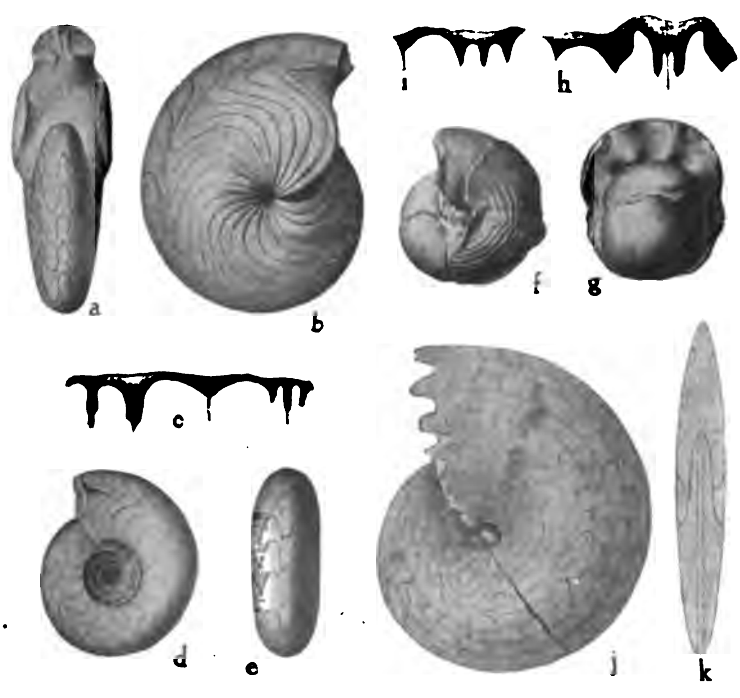


FIG. 1382. — Mississippian goniatites and ceratite. *a–c*, *Aganides rotatorius*, internal mold of shell ×½, and suture enlarged (Kinderhook and Waverly); *d–e*, *Muensteroceras oweni*, internal mold of shell ×½ (Kinderhook); *f–i*, *Goniatites striatus*, internal mold with part of the shell preserved, ×½, and external (*h*) and internal (*i*) parts of the suture, enlarged (St. Louis and Chester); *j–k*, *Prodromites gorbyi*, internal mold, showing the ceratitic suture, ×½ (Kinderhook-Chouteau limestone). (I. F.)

is absent, but a larger-tubed form (*Michelinia*, Fig. 1374) occurs. **Bryozoa** are common, chief among them being the fenestelloid types, with strong spirally-twisted axis, which is often the only part preserved intact (*Archimedes*, Fig. 1375). Among the **brachiopods**, spirifers still occur, but they have their median fold and depression often plicated (Figs. 1369 *a, b*), or the shell-substances marked by punctations (*Spiriferina*). A very characteristic spiriferoid

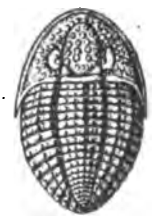


FIG. 1383. — *Phillipsia* (*Brachymetopus*) *lodiensis*, a typical Mississippian trilobite (Waverlyan). (I. F.).

is the genus *Syringothyris* with a slit tube on the inside of the beak of the pedicle valve (Fig. 1377 *a, b*). Smooth elongate shells, some with spiral arm supports (*Athyris*, Fig. 1377 *c, d*), others with simple loop-like supports (*Dielasma*, Fig. 1378), are characteristic. But by far the most typical brachiopod is *Productus*, which has an extremely convex and extended or "produced"

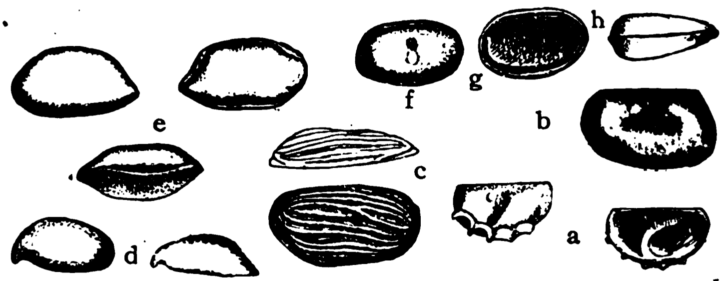


FIG. 1384. — Characteristic Mississippian ostracods. *a*, *Ctenobolbina loculata*, right exterior and left interior of valves, X14 (Kinderhook); *b*, *Beyrichiella confluens*, left valve, X14 (Chester shales); *c*, *Kirkbya costata*, X10 (Warsaw of Illinois, "Lower Carboniferous limestone" of England); *d*, *Cypridina herzeri*, left valve, X10 (Keokuk); *e*, *Bairdia cestriensis*, left, right, and dorsal views, X14 (Chester shale); *f–h*, *Cytherella ovaliformis* (Chester). (I. F.)

pedicle valve and a shallower, concave brachial valve, while the surface is often spinose (Figs. 1368 *a, b*, 1377 *k–q*). The orthis group has almost disappeared.

Pelecypods are common and of considerable variety (Fig. 1379), while **gastropods** are largely represented by the *Bellerophon* type (Fig. 1380). The group of **cephalopods** includes chiefly nautiloids (Fig. 1381) and goniatites (Fig. 1382), but some ammonitic types already make their appearance. **Trilobites**

begin to be rare, being restricted chiefly to the genus *Phillipsia* and related genera (Fig. 1383). **Ostracods**, on the other hand, are abundant (Fig. 1384). **Crinoids** are found in great numbers, the numerous species showing an increase in some cases from delicate forms in the lower to robust types in the upper beds (Figs. 1385, 1386). **Blastoids** for the first time become abundant and important, especially in some of the higher divisions, where the genus *Pentremites*

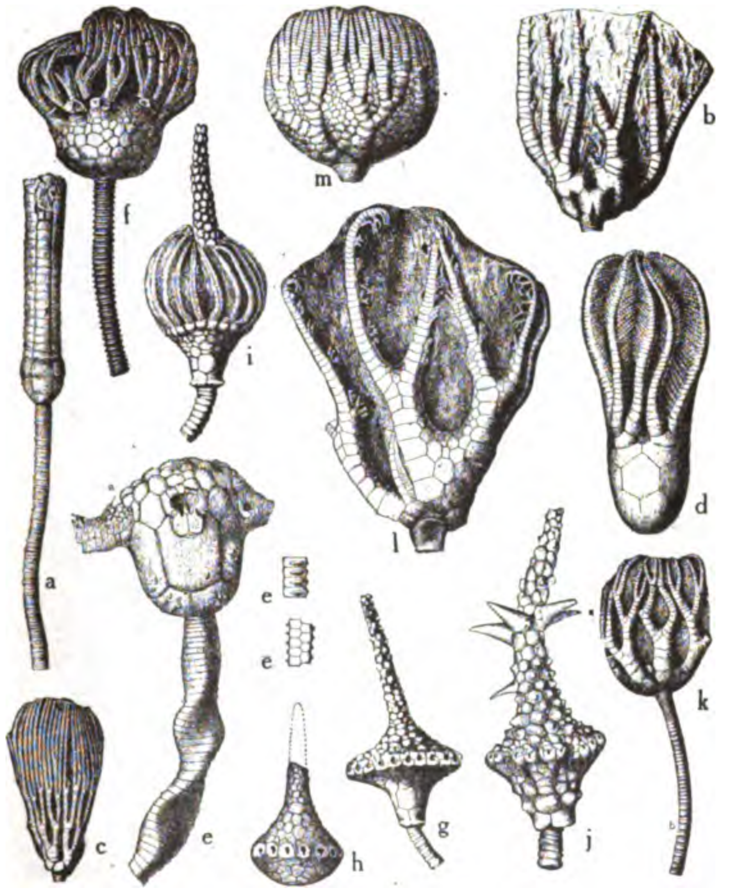


FIG. 1385. — Mississippian crinoids. *a*, *Symbathocrinus robustus*, ×½ (Keokuk); *b*, *Barycrinus hoveyi*, ×½ (Keokuk); *c*, *Woodocrinus æqualis*, ×½ (Keokuk); *d*, *Agassizocrinus dactyliformis*, ×½ (Chester); *e*, *Platycrinus halli*, with top and side views of arm fragment (*e'*, *e''*), ×½ (Burlington); *f*, *Megistocrinus nobilis*, ×½ (Kinderhook); *g*, *Eutrochocrinus christyi*, ×½ (Burlington); *h*, *Dizygocrinus euconus*, ×½ (Keokuk); *i*, *Lobocrinus pyriformis*, ×½ (Burlington); *j*, *Lobocrinus nashvillæ*, ×½ (Keokuk); *k*, *Taxocrinus communis*, ×½ (Waverly); *l*, *Onychocrinus exculptus*, ×½ (Keokuk); *m*, *Forbesiocrinus wortheni*, ×½ (Keokuk.) (I. F.)

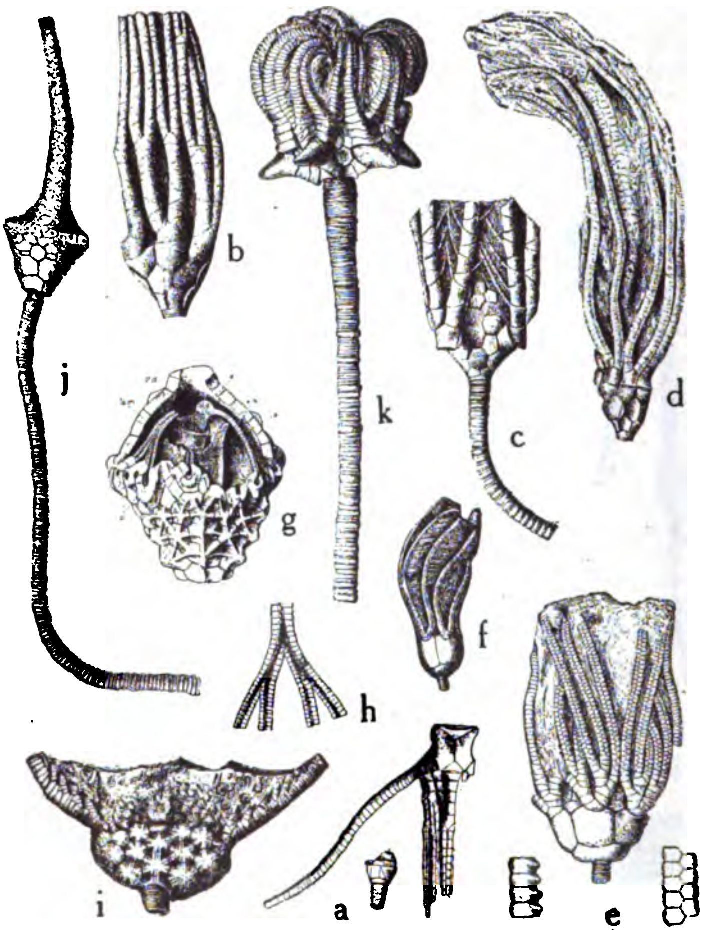


FIG. 1386. — Mississippian crinoids. *a, Halysiocrinus bradleyi*, ×½ (Keokuk); *b, Scaphiocrinus crineus*, ×¾ (Waverly); *c, Decadocrinus pleias*, ×¾ (Waverly); *d, Scytalocrinus robustus*, ×½ (Keokuk); *e, Platycrinus burlingtonensis*, ×2½, with two views of arm fragment still further enlarged (Burlington); *f, Dichocrinus inornatus*, ×½ (Kinderhook); *g, h, Cactocrinus proboscidialis*, broken calyx showing the interior, and ambulacral grooves enlarged (Burlington); *i, Steganocrinus sculptus*, ×½ (Burlington); *j, Macrocrinus verneuilianus*, without arms, ×¾ (Burlington); *k, Taxocrinus thiemii*, ×½. (I. F.)

predominates (Fig. 1387 *g–i*). Other types also occur (Fig. 1386 *d–f*). **Echinoids** are found, but they are mainly spherical masses with more than two (often many) columns in each area (*Melonites*, Fig. 1388). **Fish** remains (chiefly teeth, Fig. 1389) also occur in some horizons but they are probably of types which were mainly inhabitants of the rivers. The most marked advance in life is shown in the presence of land vertebrates, whose foot-prints are found in the continental strata, especially those of the Mauch Chunk formation of North America. These belonged to amphibians, and heralded the culminating event in Palæozoic life history, the advent of the land-life from its ancestors

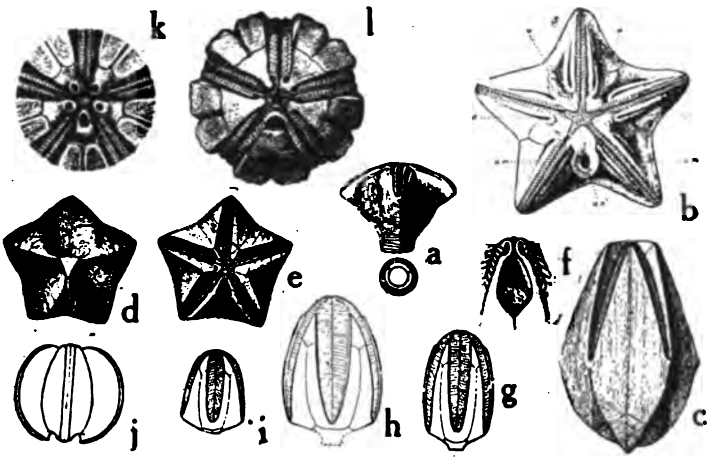


FIG. 1387. — Mississippian blastoids. *a*, *Orophocrinus stelliformis*, side and stem views, ×¾; *b*, summit view of same enlarged, showing ambulacral furrows (*am*), oral vault (*v*), spiracles (*s*), and anal aperture (*an*) (Burlington); *c–f*, *Tricœlocrinus woodmani*, side, basal, and summit views, ×¾, and anal portion (*f*), ×1½ (Warsaw); *g*, *h*, *Pentremites elongatus*, slender and robust forms (Burlington); *i*, *Pentremites conoideus* (Keokuk, Warsaw, and St. Louis); *j–k*, *Granatocrinus norwoodi*, *j*, outline, *k*, central part of the summit enlarged (Burlington); *l*, *Cryptoblastus melo*, summit, ×2½ (Burlington). (I. F.; see also Figs. 949–951, pp. 158, 159.)

in the waters. This was the beginning of the population of the lands by air-breathing animals.

Plants. — Land plants of highly developed types, but belonging mainly to the calamites and lycopods as well as fern-like types, are common in the terrestrial deposits of the Mississippian in both hemispheres. Characteristic American forms are *Sphenopteris* (Fig. 1390 *a*) and *Archæopteris* (Fig. 1390 *b*), while the Culm of Europe contains *Asterocalamites* (Fig. 1390 *c*), and *Lepidodendron* and the ferns *Sphenopteridium* (Fig. 1390 *d*), and *Cardiopteris* (Fig. 1390 *e*). These ferns are all closely related to the types which became dominant in Pennsylvanian time.

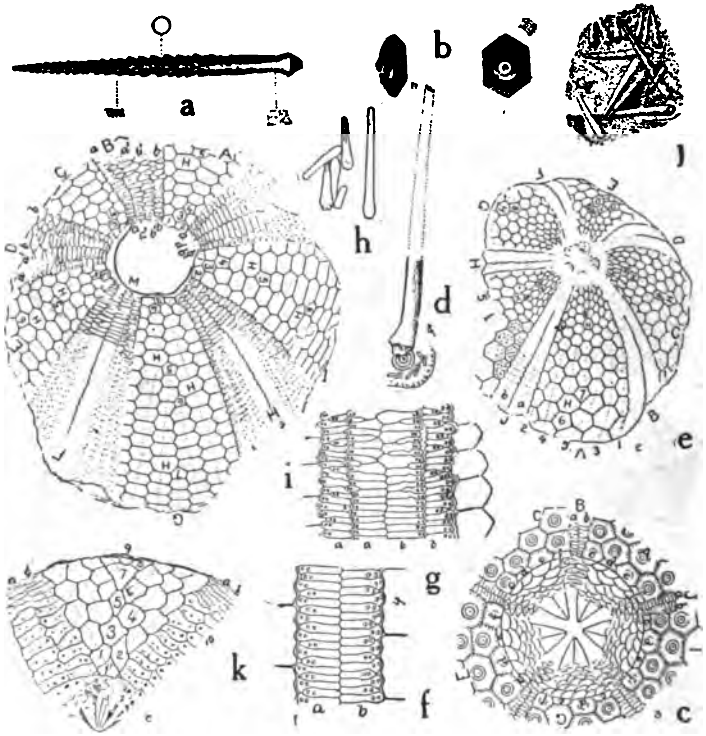


FIG. 1388. — Mississippian echinoids. Outline drawings to show the arrangements of plates, by which they are distinguished. (For general appearance see Fig. 961, p. 165.) *a*, *b*, ***Archæocidaris shumardiana***, spine (*a*) and two views of a plate (*b*), ×1½ (Keokuk and Warsaw); *c*, ***Archæocidaris wortheni***, restoration of ventral surface (*a*, *b*, ambulacral, *c–f*, interambulacral plates) (St. Louis); *d*, spines (large and small) and plate with spine-boss, of the same; *e*, ***Rhoëchinus gracilis***, a partial internal mold, showing order of appearance of interambulacral plates (Burlington); *f*, ***Rhoëchinus elegans***, ambulacrum enlarged; *g*, ***Oligoporus danæ***, ambulacral area, showing two partial additional columns of plates; *h*, spines of same, ×3 (Keokuk); *i*, ***Melonites multiporus***, a part of the corona from oral or ventral end, showing arrangement of plates; *i*, spines of same, ×3 (St. Louis, see Fig. 961); *k*, ***Lepidechinus rarispinus***, oral aspect, showing single interambulacrum increasing to eight (Waverly). (Chiefly after Jackson, from ***Index Fossils***.)

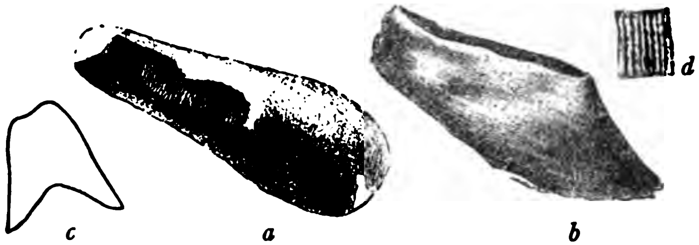


FIG. 1389. — *Ptyctodus calceolus*, teeth of a fish, abundantly preserved in the Lower Mississippian strata of North America. *a*, crown; *b*, side view; *c*, profile section; *d*, magnified portion of triturating surface.

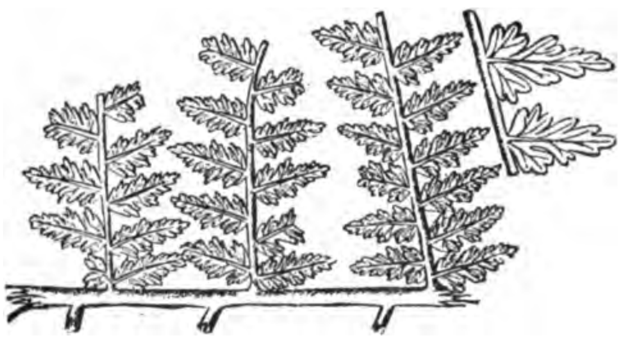


FIG. 1390 *a*. — An American Mississippian fern (*Sphenopteris tridactylites*). (After Lesquereux.)

FIG. 1390 *b*. — An American Mississippian fern *Archaeopteris minor*, Mauch Chunk. (After Lesquereux.)

FIG. 1390 c. — *Asterocalamites scrobiculatus*, from Culm of western Europe. (Kayser.)

FIG. 1390 d. — A Mississippian fern, *Sphenopteridium dissectum*. Culm of Europe. (Kayser.)

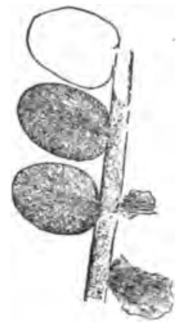


FIG. 1390 e. — *Cardiopteris polymorpha*, Culm of Europe. (Kayser.)

CHAPTER XXXVII

THE PENNSYLVANIAN OR CARBONIC SYSTEM

THE tendency in the events which stands out most prominently as we review the Palæozoic history of the earth, especially that of the northern hemispheres, is the progressive change from widespread inundations by the sea through a series of oscillations to more and more extensive emergence of the lands and contraction of the interior seas. This is most marked in eastern North America and in western Europe, where continental sediments became more prominent as Palæozoic time advanced. Appalachia and the western European continents were continually rising, and the sediments brought from them were spreading farther and farther over the lands. With the increase in land, plant life spread far and wide and extensive coal swamps came into existence. These were heralded during the Devonian, became more pronounced in the Mississippian, and culminated in the Pennsylvanian, which was probably the greatest coal-forming period the world has ever seen. In eastern North America these conditions continued into Permian time, and the whole series of changes terminated in a colossal deformation of the strata which had accumulated up to this period. This was the birth of the Appalachian Mountains in the east and of the Palæo-Cordilleran Mountains in the west. In western Europe the mountain-making disturbances began towards the close of the Mississippian and continued more or less through the Pennsylvanian, while the Permian was a period of partial readjustment and of widespread development of arid conditions with salt deposition. Somewhat similar climatic conditions also existed in western North America. In the present southern hemisphere we meet with the extensive development of glacial conditions toward the close of the Palæozoic and these may have also existed to some extent in the present northern hemisphere.

North America

With negligible exceptions the Pennsylvanian as well as the Permian formations of eastern North America are all continental sediments and represent a series of alluvial fan, flood-plain, and

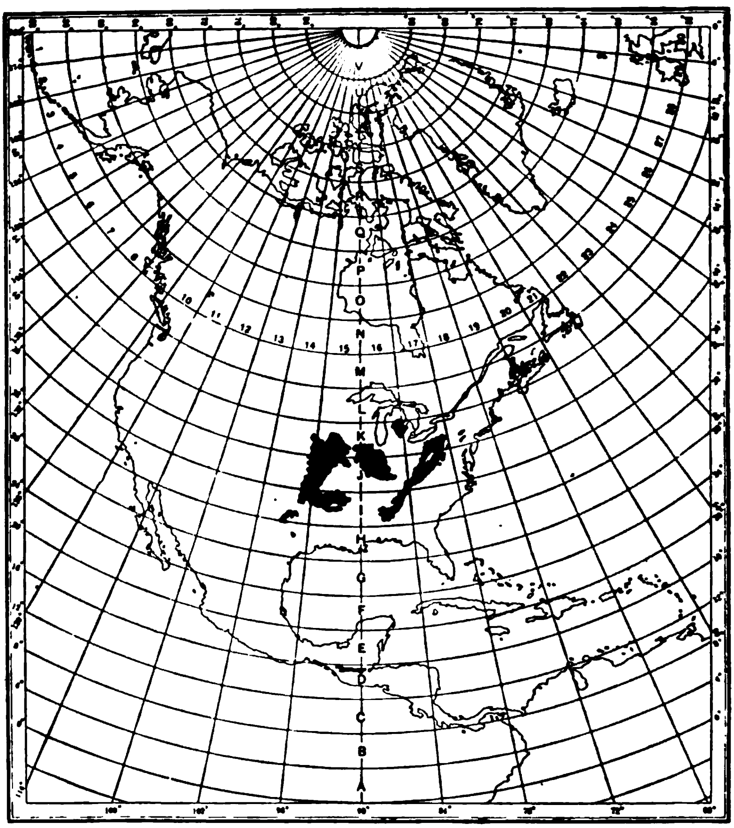


Fig. 1391 *a*. — Map showing the outcrops of Pennsylvanian rocks in North America. (After Bailey Willis.)

swamp deposits, of material derived by the erosion of the continually rising Appalachian oldland. During the early progress of such deposition in the Appalachian geosyncline, the central area, which previously received the marine Mississippian deposits, was undergoing active erosion, so that a considerable portion

of the older rocks was again removed, especially in the more northern region, and when later the first deposits of the Pennsylvanian reached this district, they came to rest disconformably upon various members of the older series. This is well illustrated

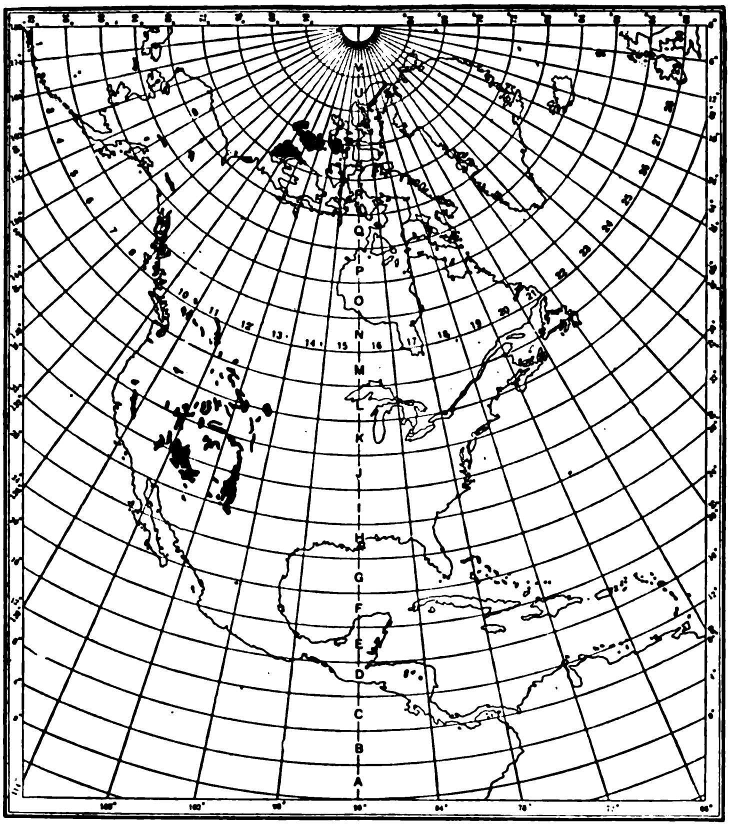


FIG. 1391 *b*. — Map showing the outcrops of the undivided Carboniferous rocks of North America. (After Bailey Willis.)

in the following north and south section in Indiana (Fig. 1392), a section which with variations could be duplicated in Illinois, where the erosion in the north has cut down even to the Devonian, upon which formation the first of the Pennsylvanian deposits rests.

Still farther west, however, marine conditions continued, especially in the western part of the Cordilleran geosyncline and

later on in the eastward extension of this in the Kansas-Nebraska region, which had by this time become more or less distinct from

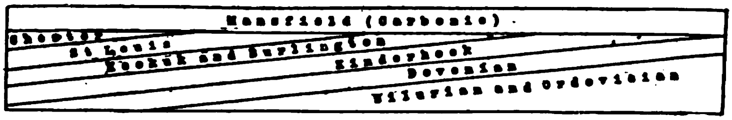


FIG. 1392. — Diagrammatic north-south section in Indiana or Illinois, showing the disconformable relationship of the basal Carbonic sandstone (Mansfield), which rests upon the beveled edges of the several Mississippian formations, showing profound erosion before the deposition of the sandstone. (Original.)

the western geosyncline by the rise of the Rocky Mountain protaxis (Map, Fig. 1399).

Stratigraphic Succession

The complete succession of the Permo-Carbonic continental deposits in the Appalachian geosyncline is as follows:

Dunkard or upper Barren series (Permian)	Of the bituminous region.
Monongahela or upper Productive series	
Conemaugh or lower Barren series	
Allegheny or lower Productive series	
Kanawha or lower Productive series	Of the Appalachian Mountain region.
Pottsville series	

The Pottsville Series. — This is a coarse sandstone and quartz pebble conglomerate which in the Appalachian region everywhere lies at the base of the Pennsylvanian series, and from its resistant character forms mountain ridges or constitutes the summit formation of extensive plateaus (Fig. 1397). It is known by various names in different sections but is everywhere a deposit formed by rivers from Appalachia, and besides being free from marine organic remains, except in its marginal portions, where the beds entered the sea, it frequently shows repeated and pronounced torrential cross-bedding. There are at least two centers of accumulation where the earliest known portions of the series were deposited and from which the successive beds spread in all directions, overlapping one another away from the source of supply (Fig. 1393). One of these centers is near the type region (Pottsville) on the Schuylkill River in Pennsylvania, where the beds now form typical Appalachian ridges (Fig. 1394). The second center lies in the Pocahontas region of southern Virginia and West Virginia. In both cases the formations are from 1200 to 1500 feet in thickness, but they

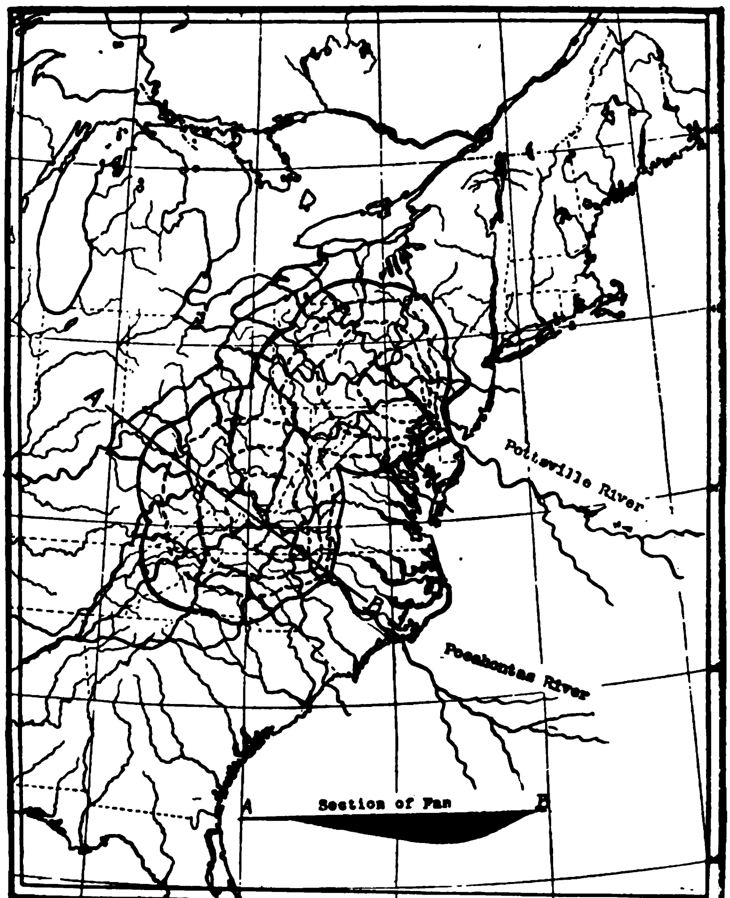


FIG. 1393. — Map of the alluvial fans of early Carbonic time, the remnants of which now constitute the Pottsville, Lee, and other conglomerates of the Appalachian region, the Olean conglomerate of New York, and the Sharon of Ohio. (Original.)

probably extended much farther east at one time and had a corresponding increase in thickness. The radial spreading and overlap of the four principal subdivisions is well shown by a study of the sections of the formation (Fig. 1395). The material is clearly derived from Appalachia, which was the only land mass at that time capable of furnishing such sediment. The pebbles are in general much larger and of a greater variety of material in these centers of origin, decreasing in size as we pass away and becoming

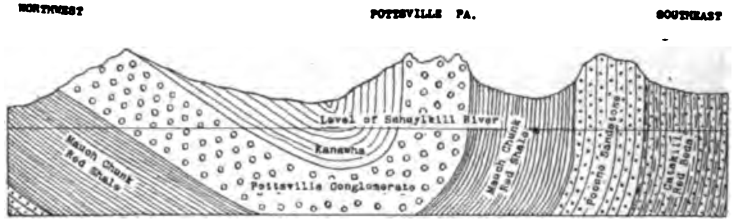


FIG. 1394.—Section of the formations along the Schuylkill River, near Pottsville, Pa., showing the relationship of the Upper Devonian (Catskill), the Mississippian (Pocono and Mauch Chunk), and the Pottsville conglomerate and higher Coal-measure strata. (Original.)

mostly pure, well-rounded quartz. The lowest division (*Pocahontas*) is represented only in the two eastern districts noted; the next division overlaps it from both centers in all directions, away from the source of supply, and comes to rest upon the somewhat eroded surface of the Mississippian, beyond the area covered by the lower division. The third division overlaps the second in the same way, the beds of the two fans becoming more or less confluent in the region between the two centers; and the fourth division overlaps the third and has the greatest extent. This

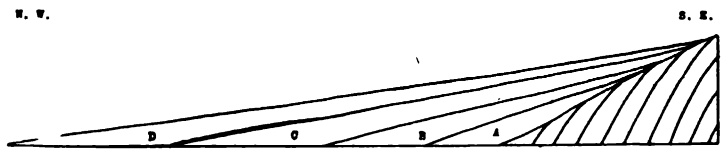


FIG. 1395.—Ideal section of the Pottsville alluvial fan, showing the northwestward overlap of the successive members. The overlap is away from the source of supply, which was Appalachia on the east. (Original.)

division alone is represented in southwestern New York (*Olean conglomerate*, Figs. 1396, 1397), and in western Pennsylvania and Ohio (*Sharon conglomerate*). The several divisions are distinguished by their characteristic plant-bearing beds, which are either present as intercalated layers, or form the roof shales of more or less important coal seams in the series.

of the older rocks was again removed, especially in the more northern region, and when later the first deposits of the Pennsylvanian reached this district, they came to rest disconformably upon various members of the older series. This is well illustrated

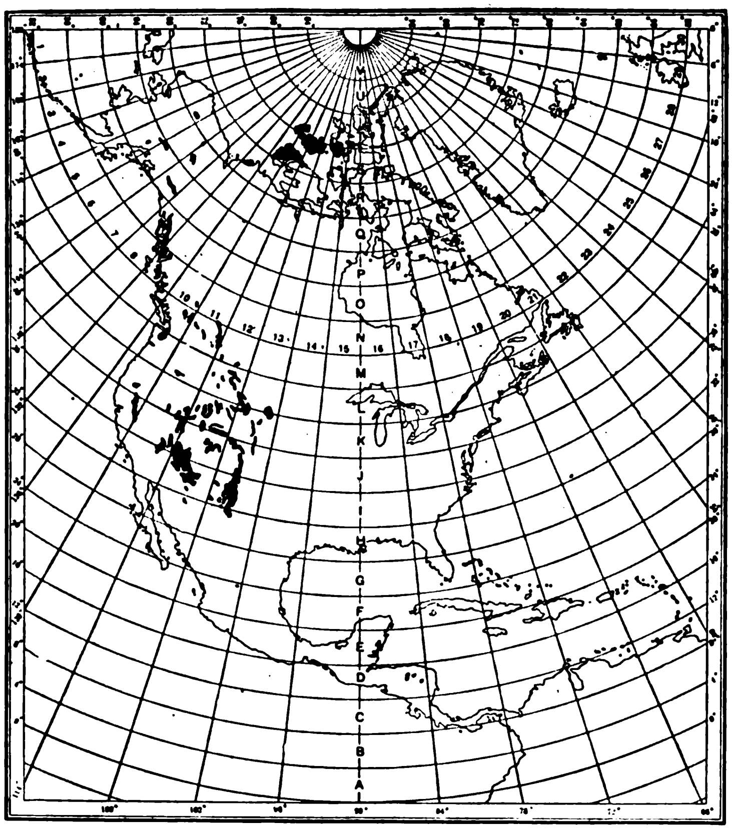


FIG. 1391 *b*. — Map showing the outcrops of the undivided Carboniferous rocks of North America. (After Bailey Willis.)

in the following north and south section in Indiana (Fig. 1392), a section which with variations could be duplicated in Illinois, where the erosion in the north has cut down even to the Devonian, upon which formation the first of the Pennsylvanian deposits rests.

Still farther west, however, marine conditions continued, especially in the western part of the Cordilleran geosyncline and

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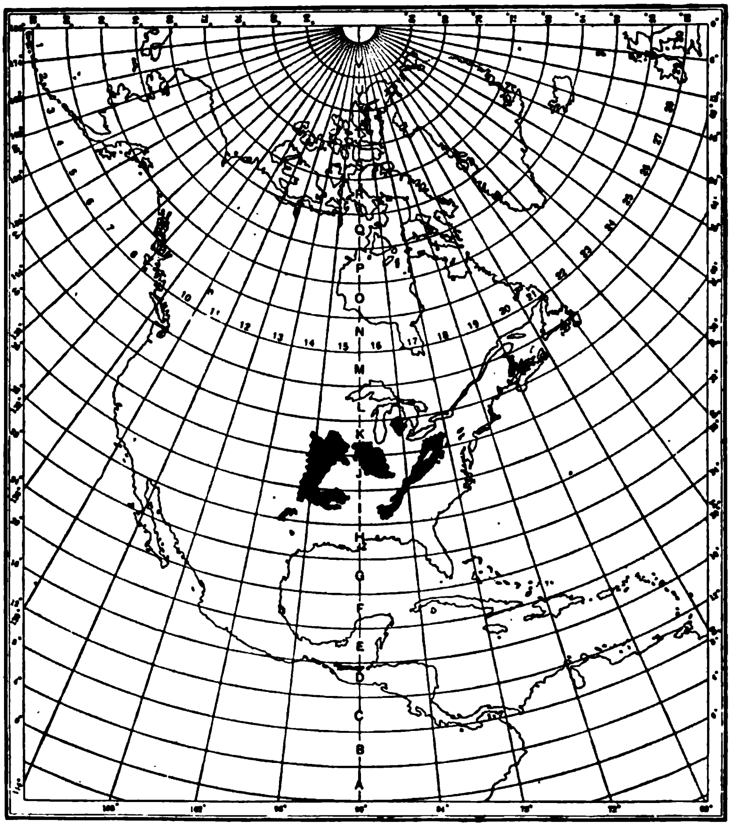

Fig. 1391 a. — Map showing the outcrops of Pennsylvanian rocks in North America. (After Bailey Willis.)

swamp deposits, of material derived by the erosion of the continually rising Appalachian oldland. During the early progress of such deposition in the Appalachian geosyncline, the central area, which previously received the marine Mississippian deposits, was undergoing active erosion, so that a considerable portion

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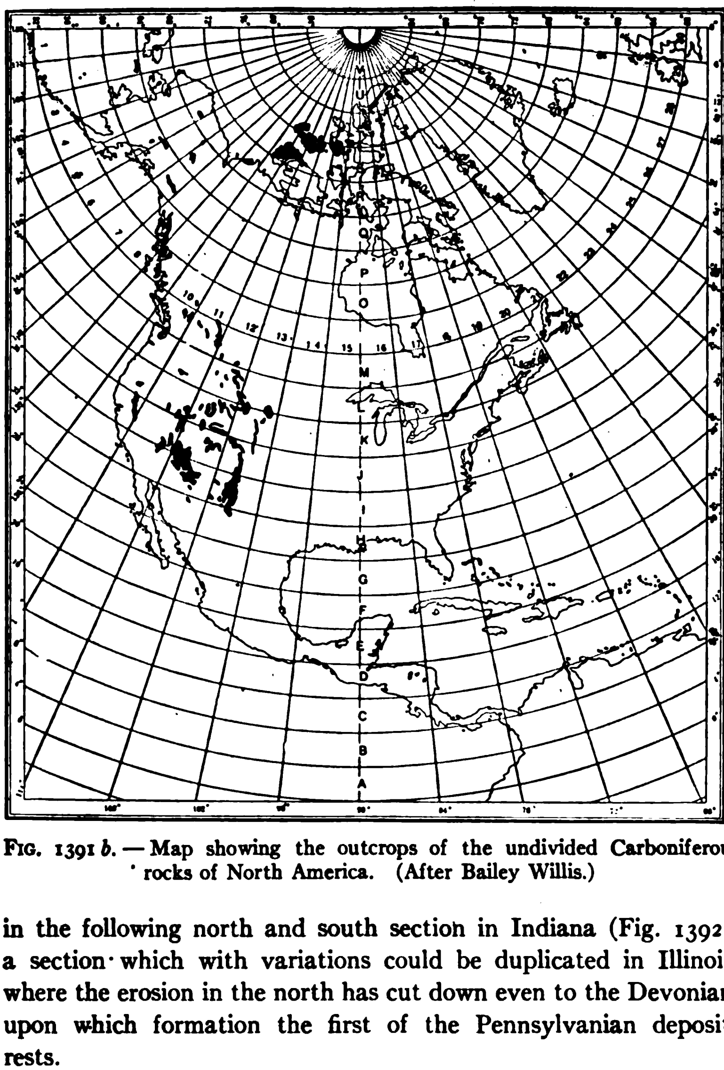

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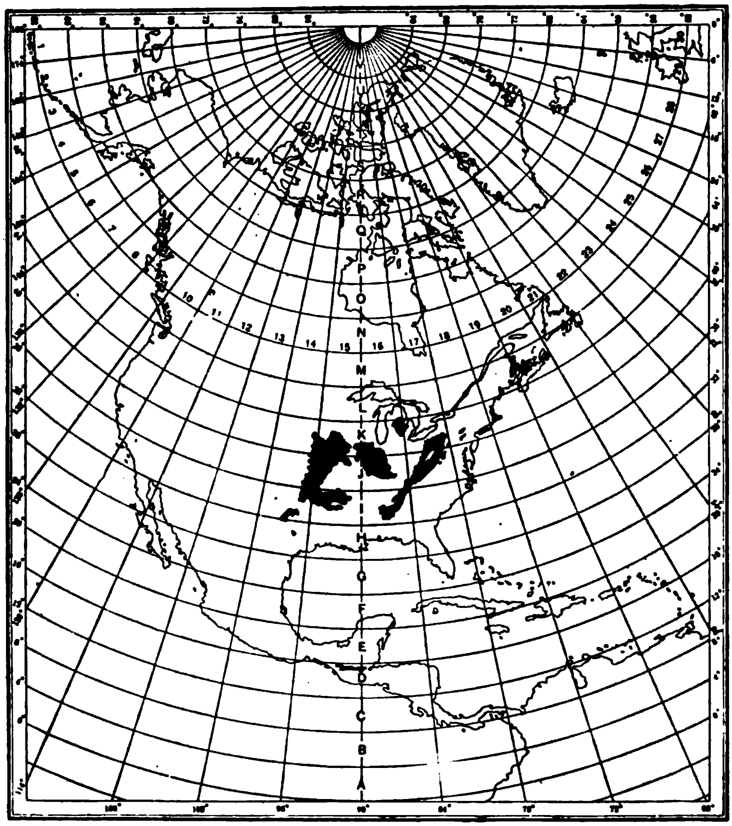

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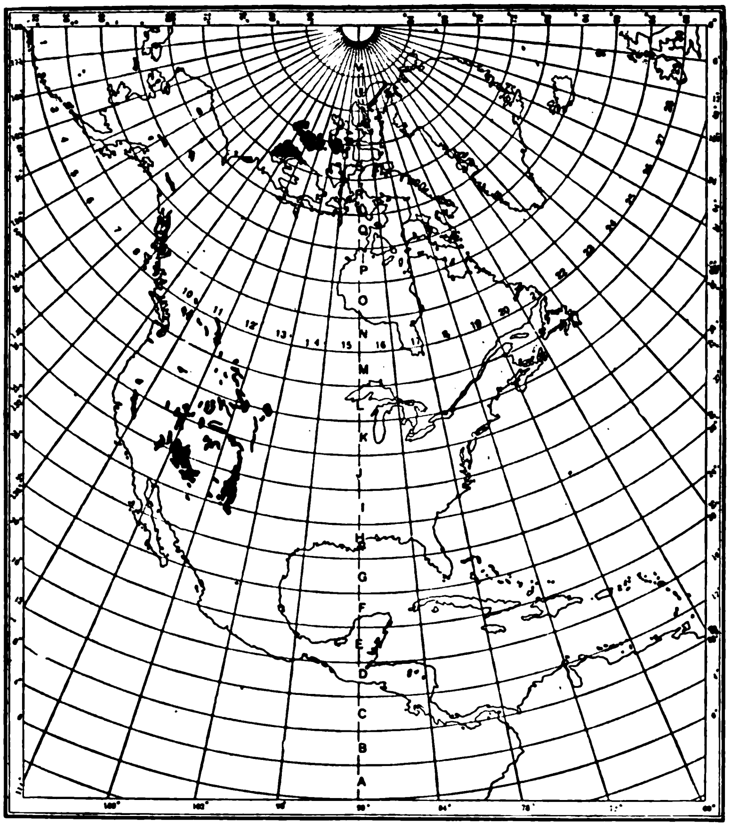

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Still farther west, however, marine conditions continued, especially in the western part of the Cordilleran geosyncline and

probably represented the southern end of the Rocky Mountain protaxis, the Lower Pennsylvanian limestone is succeeded by a millstone grit, that is, a quartz conglomerate, and above this follows an alternation of marine and continental beds, the latter with calamites, showing oscillatory conditions. In the Zuñi Plateau region of New Mexico to the northeast of the preceding locality the Red Wall limestone is overlapped by the bright red lower Aubry sandstones which rest directly upon the granite. But in the center of the trough marine conditions prevailed through most of the Pennsylvanian, and great deposits, 6000 to 7000 feet thick and chiefly of limestones, were there formed and are now exposed in the more recent uplifts, such as those of the Wasatch and other mountains. Terrigenous clastics succeed these limestones, showing the gradual shoaling of the trough towards the close of the period.

It is owing to the essential separation of the Kansas sea from the Cordilleran geosyncline that the faunas of the two basins are to a certain extent distinct, though there are many species in common between them. The fauna of the western basin has also much in common with that of Europe and Asia.

Europe and Asia

Subdivisions. — The Upper Carboniferous or Carbonic of Europe, with which that of Asia is closely correlated, admits of a threefold division as follows:

Upper Carbonic or **Ouralian** (marine); **Stephanian** or **Ottweilian** (non-marine).

Middle Carbonic or **Upper Moscovian** (marine); **Westphalian** or **Saarbrückian** (non-marine).

Lower Carbonic or **Lower Moscovian** (marine); **Namurian** (partly marine); **Waldenburgian** (non-marine).

Preceded conformably by Mississippian or Dinantian.

Stratigraphic Development

We must recall once more the general geographic conformation of the continents of Europe and Asia in later Palæozoic time. On the northwest the continental mass of Atlantica occupied the greater part of the British Isles, Scandinavia, Finland, and a part of the Russian land. This included the old Baltic embayment of Silurian and earlier time which, by the folding and elevation, had been added to the land mass of Atlantica, while the main geosyncline of deposition had migrated farther to the south and east. From this land mass the main Devonian sediments of western Europe were derived, these being spread out in the geosyncline. The sea transgressed southward over the present Mediterranean region to the borders of the old African continent. In Asia the main land mass was the Siberian basin (the site of Silurian and older sediments), which had become surrounded by a relatively continuous mountain system, outside of which again lay a new geosyncline. On the west of the Siberian mass this geosyncline lay in the region now occupied by the Ural Mountains. On the south it lay approximately along the Chinese border and on the east it extended through east Siberia to Alaska. These were the regions in which the chief Devonian, Mississippian, and Carbonic marine strata were deposited.

At the opening of Carbonic time the western European region became divided into two basins by the rising of a land barrier which extended from central France to Bohemia on the one hand and westward on the other for an unknown distance into the present Atlantic, south of England, and Ireland (Armorican land mass). During the rise of this land mass some of the older rocks, including the Mississippian, were folded, and subsequent erosion truncated these folds. This land barrier defined the coal basins of northern Europe on the south and became one of the chief sources of supply of clastic sediment, so much so that the sea was practically excluded from much of these northern basins. On the south, however, the marine waters continued unabated in the Mediterranean basin, which joined the Ural and central Asiatic geosynclinal depressions in which the sea likewise was dominant.

The northern basin apparently was closed on the west where the Armorican land barrier joined the land mass of Atlantica. It opened to the eastward, however, where it joined the Ural depression. At first the sea still lingered in this basin; but soon it withdrew eastward, leaving the western area subject to continental sedimentation and the formation of coal swamps. This withdrawal is well shown in the British succession, where the Mississippian limestone is succeeded by shallow water deposits (*Yoredale* beds of England, *Gannister* group of Scotland), and these are followed by the continental Millstone Grit, a deposit of the type of the American Pottsville. Then follow the river and flood-plain deposits which inclose the coal beds and some of which still contain brackish-water organisms, though most of them are of fresh-water origin. While the Millstone Grit was forming as a continental deposit in Britain, Belgium and the north of France were still covered by the sea. Here is found a shallow-water series of carbonaceous muds at the base (*Chokian* series), chiefly marine and estuarine, and these are succeeded by sands, partly of subaërial origin, with from four to eight marine intercalations. This entire series of older Carbonic deposits of Belgium (*Namurian*)

Fig. 1400. — Quarry in the coal-beds (Stephanian) of the Commentry basin, France. (After Haug.)

is succeeded by the lower Coal-measures, 1000 meters thick, the lower part of which contains eight coal seams and two marine intercalations and many brackish- and fresh-water beds, while the upper part has fifty-one coal seams but is without marine intercalations (Fig. 1400).

Still farther east, in Germany, the Mississippian beds are followed by 200 meters of pure marine Carbonic beds with goniatites, and these pass upward into non-marine sands 1000 meters thick which still contain some marine intercalations but no coal beds. Then follow the main coal deposits (including those of the Saar Valley and of Westphalia) with a thickness of over 3000 meters, but still with a number of marine intercalations (Fig. 1401). Above this lies the non-marine *Ottweiler* series, which in places marks the beginning of increasing aridity as shown by the presence of exten-

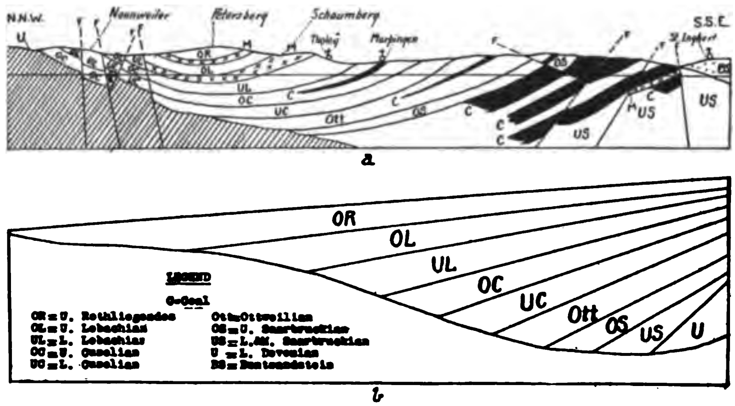


FIG. 1401.—*a*, Cross-section of the Carbonic and Lower Permian (Rothliegendes) beds of the Saar-Nahe coal region of western Germany, showing their relation to the older Palæozoic rocks. (Modified after Nasse and Kayser.) *M*, Lava (melaphyr); *C*, coal-beds; *F*, faults.

b, Reconstruction of the section to show the relationships of the strata at the time of deposition. The overlap is from south southeast, to north northwest, or away from the source of supply, which was in the Variscian mountains of the period (Fig. 1427). (Original.)

sive red beds. Thus there is shown a gradual eastward retreat of the sea from the northern basin and the replacement of marine by continental sediments, while the repeated readvances of the sea extended westward to a diminishing extent. In the Russian region,

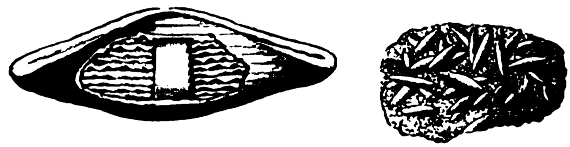


FIG. 1402 *a*. — *Fusulina cylindrica*, Carbonic. Natural size on rock, and a specimen enlarged and partly worn to show interior.

however, marine conditions prevailed throughout, and an enormous series of marine strata, estimated at 18,000 meters in thickness, and including the coal beds of the Donetz basin, were deposited. A remarkable character of these deposits, especially the middle division, is the presence of a large number of characteristic species which are equally abundant in the Pennsylvanian

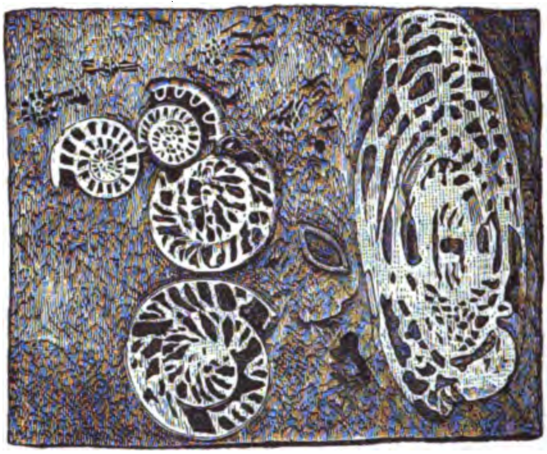


FIG. 1402 *b*. — *Fusulina* (×9), polished slab of limestone showing shell in section. Carbonic.

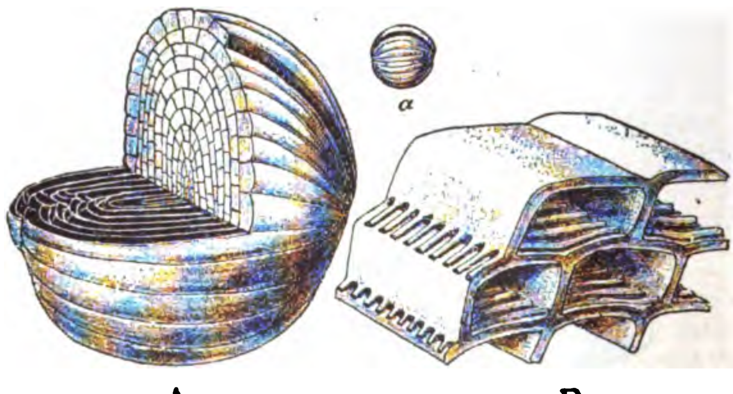


FIG. 1403. — *Schwagerina verbecki*, Carbonic. *A*, diagrammatic view; *B*, plan of structure; *a*, natural size.

limestones of western North America. Foraminifera, especially the rice or grain-shaped *Fusulina* (Fig. 1402) and the more globular form *Schwagerina* (Fig. 1403), play an important part in the formations of the limestones in both regions.

The following table (modified from Kayser) shows the succession of Carbonic beds of Europe.

	Western Europe	Central Russia	Ural-Timan	Spitzbergen	Eastern Alps
Carbonic or Coal-Measures	Upper or Ottweiler beds	Schwagerina beds (Fig. 1403) Beds with *Productus cora* (Fig. 1408 *e, f.*)	Schwagerina beds (Fig. 1403)	Limestones with *Spirifer*	Schwagerina beds Auernig beds
	Middle or Saarbrückian beds	Beds with *Omphalotrochus whitneyi* Beds with *Spirifer marcoui*		Limestones with corals	absent
	Lower or Waldenburgian beds	Limestone with *Spirifer mosquensis* (Fig. 1409)	Beds with *Sp. mosquensis* and *Fusulina cylindrica* (Fig. 1402)	*Fusulina* limestone with *Spirifer mosquensis* (Fig. 1409)	
Mississippian	Dinantian Marine series	Limestone with *Productus giganteus* (Fig. 1368 *a*) etc. Coal-bearing beds Sandstones, shales and limestones in part with marine fauna	Limestone with *Productus striatus* Limestone with *Pr. giganteus* Plant-bearing sandstones and shales Limestone with *Productus mesolobus*	Beds with Culm flora	Carboniferous Limestone or Culm

Towards the close of this limestone-forming era, clastic sediments again became abundant, forming a transition to the Permian deposits.

Limestones and some clastic beds, essentially with the faunas of the Russian region, are found throughout southern Europe in the Mediterranean basin and extend eastward through central and eastern Asia.

Orogenic Disturbances

The mountain-forming disturbances which marked the opening of the European Carbonic continued at intervals in the northern European region, and culminated in the formation of the main European Palæozoic mountains. The Carbonic strata were involved in these disturbances and they are to-day much folded and faulted, especially in Belgium. Two main chains of these Alps are recognizable, both joining in central France (Fig. 1427, p. 508). One, the Variscian chain, extended northeastward in a great arc around the northern end of Bohemia to the Sudetian Mountains and perhaps beyond. The other, the Armorican chain, extended westward through Brittany, southwestern England, and Ireland. With the final rise of these mountain chains the northern basin became completely isolated, and as these mountains were of sufficient height to shut out the moisture-bearing winds, more or less arid conditions came to prevail in that area, as reflected by the character of the succeeding deposits formed there, which include not only red beds but the great North German salt deposits.

General Character of the Carbonic (Pennsylvanian) Faunas and Floras

Marine Animals

The marine faunas of the Carbonic are, on the whole, of very distinctive character when we compare them with the faunas of the older systems, especially the pre-Mississippian faunas. As might be expected, there are certain marked affinities between the Mississippian and Carbonic faunas, while there are even more pronounced affinities between the Carbonic and Permian marine faunas. Indeed in some sections a distinction between Carbonic and Permian on the basis of marine faunas is scarcely possible, because many of the characteristic Carbonic types continue into the Permian strata, and they therefore serve as index fossils only of the post-Mississippian horizons of the Palæozoic.

Fig. 1404. — *Lophophyllum profundum*. Carbonic.

Foraminifera. — These are well represented by a number of types, most prominent and characteristic among which is *Fusulina*, readily recognized by its form and size, which are like that of a grain of rice, and by its structure (Fig. 1402). This shell often makes up entire limestone masses, and may be considered a positive index fossil of the Carbonic or Pennsylvanian and the Permian. A shorter, more rounded form, *Schwagerina*, is equally characteristic of the higher Carbonic strata (Fig. 1403).

Corals. — These are, on the whole, uncommon in the marine Carbonic strata, but some of the ancient cup-coral types still survive. The most characteristic American forms are *Lophophyllum* (Fig. 1404), a small, horn-shaped type with a flattened columella projecting from the center of the cup, and *Campophyllum* (Fig. 1405), a larger form with flat center free from septa.

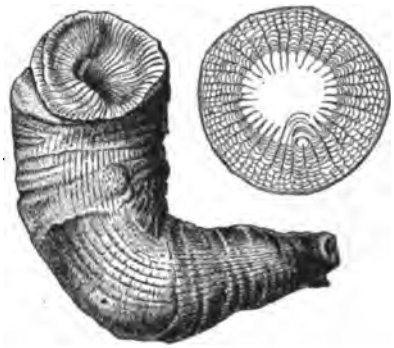


FIG. 1405. — *Campophyllum torquium*, reduced; with section. Carbonic, central U. S.

Bryozoa. — These are much less common than in the older formations, though some of the older genera still survive. The peculiar form long known as *Chætetes* (Fig. 1406) is frequently met with in European and to some extent in American deposits.

Brachiopoda. — These are distinctive in character. The orthis group is represented by a few terminal members, among them *Enteletes* (Fig. 1407 *h, i*), which is plicated along the margin. The flat-valved forms, so common in the older horizons, are here represented by massive types which lack the symmetry of the older genera (*Orthothetes* or *Derbya*, Fig. 1407 *m–p*). A plicated member of this group is also characteristic (*Meekella*, Fig. 1407 *a–c*). The characteristic stropheodontas of the Devonian have wholly disappeared. On the other hand the small broad members of this type of shell, with spines along the hinge line (*Chonetes*), are still well represented by a number of species, but all of these have more or less distinctive characters, such as a median depression (sinus), or a well-defined median fold in the convex valve (Fig. 1407). But by far the most characteristic type in this, as in the preceding (Mississippian), horizon is *Productus*, of which there is a large number of species, all with a very convex, generally spinous, large (pedicle) valve, and a flat or concave smaller valve (Fig. 1408).

FIG. 1406. — *Chætetes radians* (×½), a Carbonic coral of Europe. (Kayser.)

The genus *Spirifer* is represented by distinctive types. Most characteristic of the earlier beds is a very rotund form, regularly and simply plicated all over and recalling those of the Mississippian (*Spirifer mosquensis* of Europe, Fig. 1409, and related American forms). Higher divisions are characterized by a more extended form in which the plications are grouped or arranged in fascicles (*S. cameratus*,

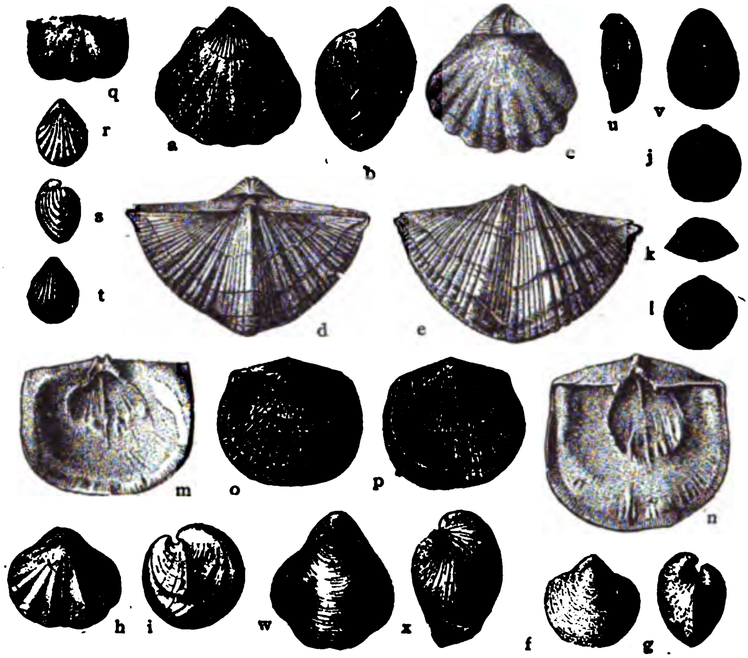


FIG. 1407. — Carbonic brachiopods. *a–c, Meekella striatocostata; d, e, Spirifer cameratus; f, g, S.* (*Martinia*) *perplexa; h, i, Enteletes hemiplicata; j–l, Rhipidomella pecosi; m–p, Orthothetes* (*Derbya*) *crassus;* (*m, n,* interiors); *q, Chonetes mesolobus; r–t, Hustedia mormoni; u, v, Dielasma bovidens; w, x, Seminula argentea.*

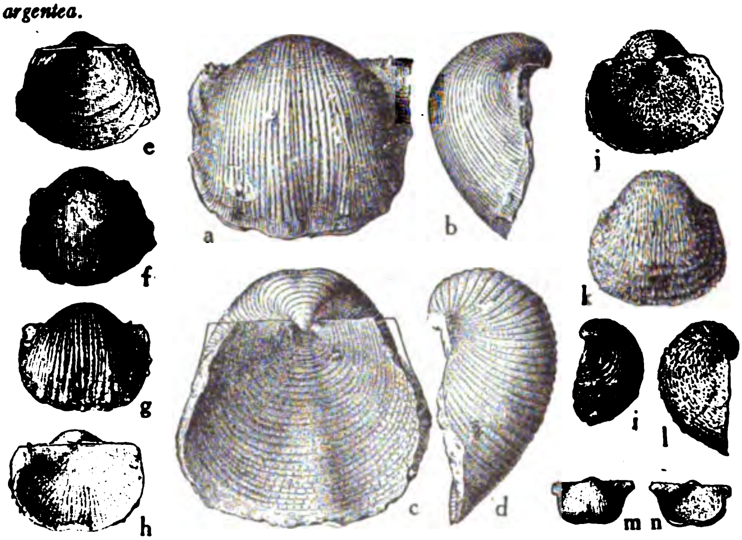


FIG. 1408. — Carbonic Producti. *a, b, Productus semireticulatus; c, d, P. punctatus; e, f, P. cora; g–i, P. costatus; j–l, P. nebraskaensis; m, n, P. longispina.*

Fig. 1407 *d, e,* called *S. fasciger* in Europe). A non-plicated subgenus with short hinge line (*Martinia,* Fig. 1407 *f, g*) also occurs in both continents. The smooth-shelled brachiopods are likewise well represented, chiefly, however,

FIG. 1409. — *Spirifer mosquensis* (×5/8). Carbonic. (Kayser.)

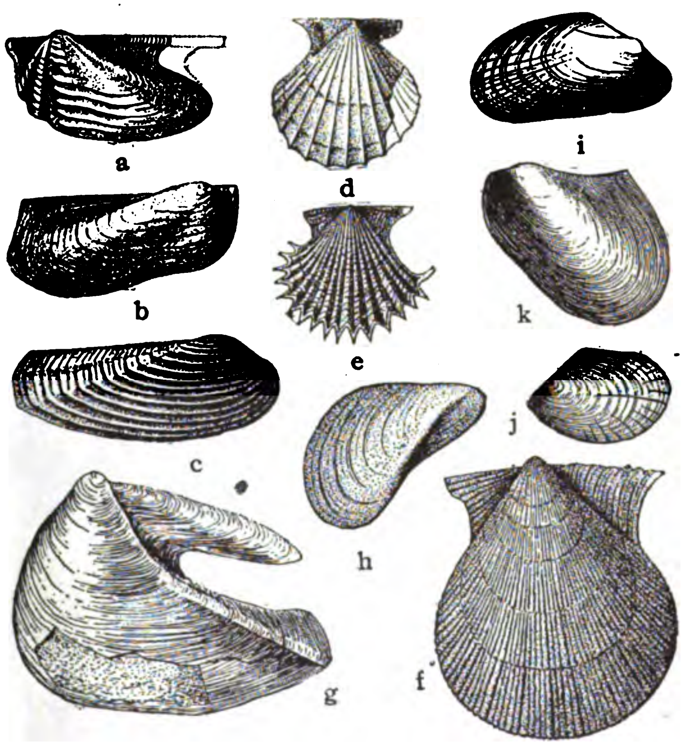


FIG. 1410. — Carbonic pelecypods. *a, Pteria sulcata,* left valve; *b, Parallelodon obsoletus,* right valve; *c, Allorisma costatum,* right valve; *d, e, Acanthopecten carboniferus,* right and left valves; *f, Aviculopecten occidentalis,* left valve; *g, Monopteris longispina,* left valve; *h, Myalina swallovi,* right valve; *i, Anthracomya elongata,* right valve enlarged (brackish or fresh water); *j, Anthracomya laevis,* left valve enlarged (brackish or fresh water); *k, Naiadites carbonarius,* left valve (brackish or fresh water). (See also Fig. 1448.) (I.F.)

by the genera *Seminula* (*Composita*, Fig. 1407 *w*, *x*) and *Dielasma* (*D. bovidens*, Fig. 1407 *u*, *v*, of America, *D. timanica* of Europe).

Pelecypods. — This class is well represented, but the characteristics of the species are not readily distinguished by the non-expert. Most marked, per-

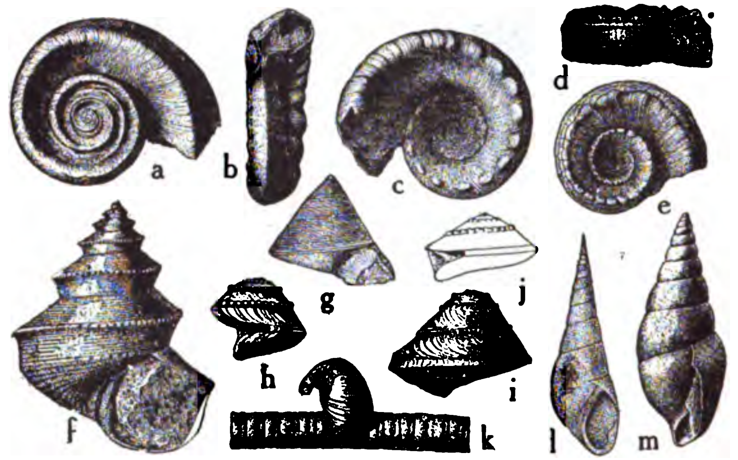


FIG. 1411. — Carbonic gastropods. *a–c*, *Euomphalus pernodosus*, about ½ natural size; *d*, *e*, *Euomphalus subquadratus*; *f*, *Worthenia tabulata*; *g*, *Pleurotomaria* (*Euconospira*) *turbiniformis*; *h*, *i*, *Pl.* (*Trepospira*) *sphærulata*, two varieties; *j*, *Pl.* (*Trepospira*) *illinoisensis*; *k*, *Platyceras parvum*, on crinoid stem; *l*, *Meekospira peracuta*; *m*, *Soleniscus regularis*. (I. F.)

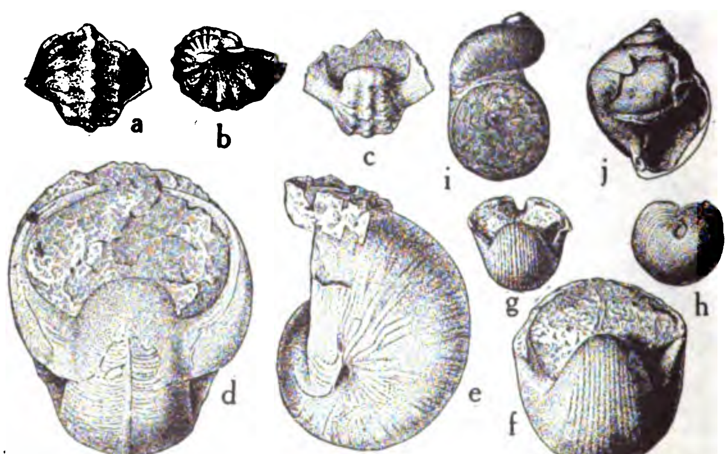


FIG. 1412. — Carbonic gastropods. *a–c*, *Bellerophon percarinatus*; *d*, *e*, *Bellerophon crassus*; *f*, *B.* (*Euphemus*) *nodocarinatus*; *g*, *h*, *B.* (*Euphemus*) *carbonarius*; *i*, *Naticopsis torta*; *j*, *Sphærodoma primigenium*.

haps, are the genera *Aviculopecten* (Fig. 1410*f*) and *Myalina* (Fig. 1410*h*), though they are not restricted to those horizons.

Gastropods. — These, too, are numerous, the most distinctive among them being the genus *Euomphalus* (Fig. 1411 *a–c*) and certain ornamented Pleuroto-

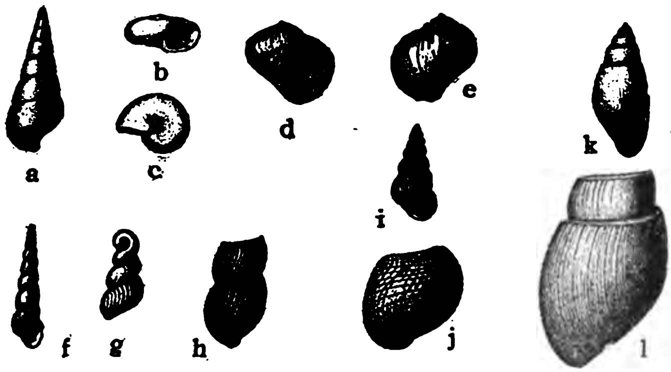


FIG. 1413. — Small types of Carbonic gastropods (natural size except when stated). *a*, *Orthonema conicum*; *b*, *c*, *Anomphalus rotulus* (×2½); *d*, *e*, *Strophostylus nanus*; *f*, *Loxonema* (*Streptaxis*) *whitfieldi* (×4); *g*, *h*, apical portion and last whorls still further enlarged; *i*, *j*, *Aclisina robusta* (×2½), with body whorl much enlarged; *k*, *l*, *Bulimorpha minuta* (×4), *l*, last whorls greatly enlarged.

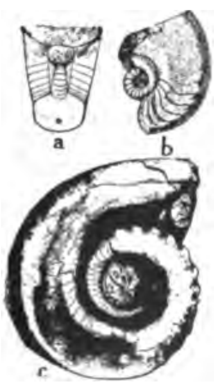


FIG. 1414.— Carbonic nautiloids. *a*, *b*, N. (*Metacoceras*) *cavatiforme*, broken so as to show the inner rounded whorls, which strongly contrast with the angular ones, and suggest Devonian or earlier types (×⅔); *c*, *M. subquadrangularis*. Adult ×½. (See further Fig. 1516, p. 572.)

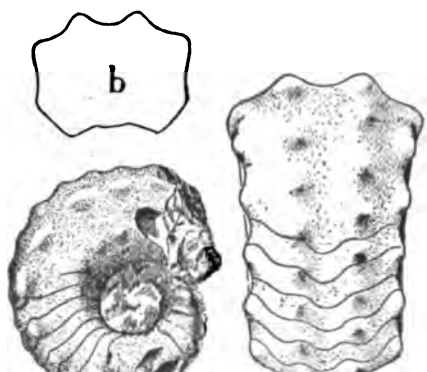


FIG. 1415. — A characteristic American nautiloid of the Carbonic and Permian. *Tainoceras occidentale* (Swallow). *a*, young, side view; *b*, adult, ventral view; *c*, section. All one-half natural size. (I. F.)

marias (*Worthenia*, Fig. 1411 *f*; *Trepospira*, Fig. 1411 *h–j*). The Bellerophons are also well represented (Figs. 1412 *a–h*). Finally the genus *Omphalotrochus* (*O. whitneyi*) is a characteristic index fossil of the middle division, both in Europe and in America. There are also many small gastropods (Fig. 1413).

Cephalopods. — This class is especially well represented by numerous ornamented and generally angular or spinous-shelled Nautiloids (Figs. 1414, 1415) and by many goniatites (Fig. 1416), generally with very complex sutures,

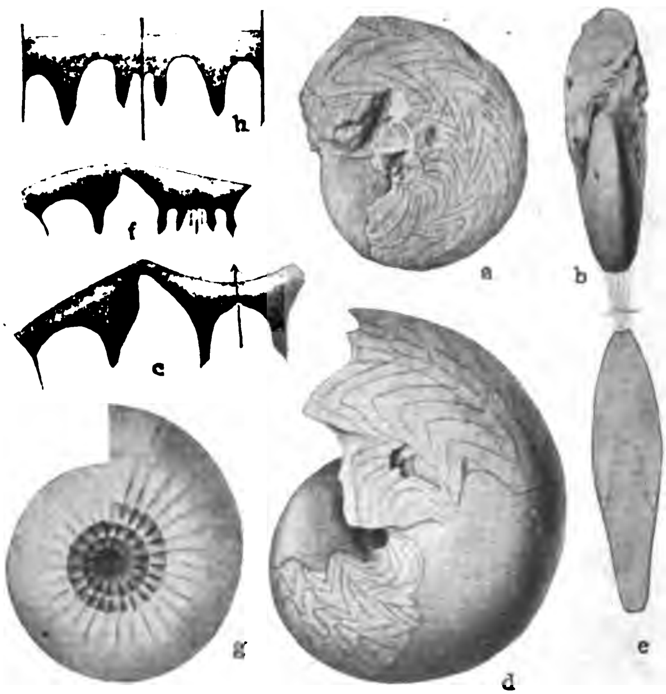


FIG. 1416. — Carbonic goniatites. *a–c*, *Gonioloboceras welleri*, internal molds of shell (two views) and suture enlarged, Ill., Texas; *d–f*, *Dimorphoceras texanum*, internal molds of shell, and suture enlarged, upper Coal-measures, Texas; *g*, *h*, *Gastrioceras carbonarium*, shell, and suture enlarged, Middle Coal-measures, Arkansas, England, Belgium, and Germany. (I. F.)

some of which are even of ceratitic type. The straight Orthoceran form, though still represented, has become very rare and is on the point of disappearance.

Trilobites and Other Crustacea. — Trilobites are represented only by the genera *Phillipsia* and *Griffithides* (Fig. 1417). The class is rare and has almost disappeared from the Palæozoic seas. Ostracods (Fig. 1418), however, still abound in some regions, and there are a number of other crustacean types, many of them inhabitants of rivers (see below).

Echinoderms. — These, too, are much modified, crinoids (Fig. 1419) being few, but a number of new echinoids, especially of the genus *Archæocidaris* (Fig. 1420), have appeared. The modern type is still unrepresented.

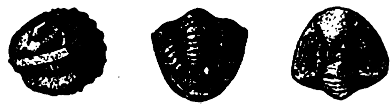


Fig. 1417. — *Griffithides scitulus.* A characteristic Carbonic trilobite, 3 views of an enrolled specimen. Natural size.

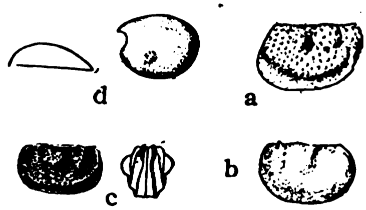


Fig. 1418. — Characteristic Carbonic ostracods. *a*, *Hollina radiata*, right valve (×14) (Cottonwood shales of Kansas); *b*, *Jonesina gregaria*, left valve (×15) (Upper Carbonic); *c*, *Kirkbya centronota*, right and end views (×14) (Cottonwood shales of Kansas); *d*, *Cypridina subovata*, left valve (×3) (Lawrence shale of Kansas). (I. F.)

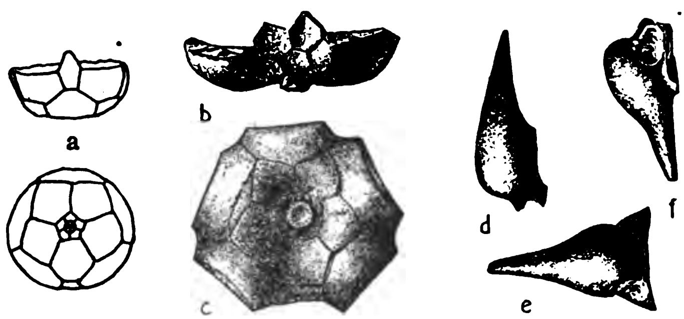


Fig. 1419. — Carbonic crinoids. *a*, *Ceriocrinus hemisphericus*, side and bottom view of calyx (Coal-measures of the central United States); *b–f*, *Eupachycrinus mooresi: b, c*, side and bottom views of calyx, *d, f*, early arm plates (costals) of the same. Coal-measures of West Virginia and Ohio (Lower Cambridge limestone). (I. F.)

River Animals

The river faunas of the Pennsylvanian contained a number of characteristic merostomes, including almost the last of the eurypterids and the remarkable genera *Prestwichia* (Fig. 1421 *d*) and *Belinurus* (Fig. 1421 *c*). The remains of these are often found beautifully preserved in the iron-stone nodules of Mazon

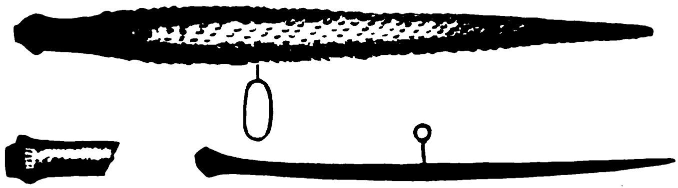


FIG. 1420. — Spines of Carbonic echinoids. *a*, *Archæocidaris agassizi*, with cross-section (×2), Coal-measures of Kansas, also Burlington of Iowa and Mo.; *b*, *Archæocidaris dininnii*, natural size with cross-section, and basal part enlarged, Coal-measures of the central United States.

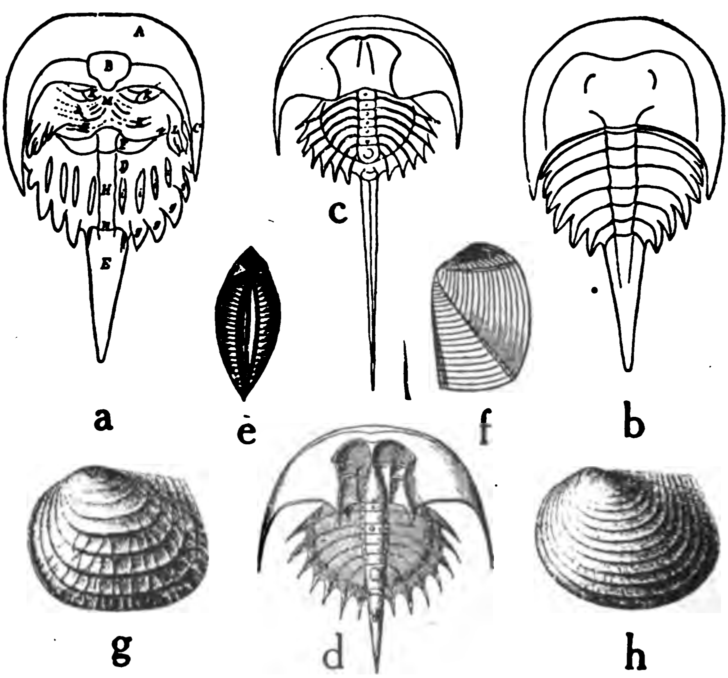


FIG. 1421. — Fresh-water merostomes (*a–d*) and branchiopod crustaceans (*e–h*) of the Carbonic. *a–b*, *Protolimulus eriensis*. Diagrams of lower and upper side (the latter theoretical). *A*, cephalic shield; *B*, ? hypostoma; *C*, genal spine; *D*, thoracico-abdominal buckler; *E*, telsen; *g*, marginal abdominal spines; *i–i*, longitudinal ridges of buckler; *KK*, portions of gnathopodes; *L*, ? foliaceous terminations of the last gnathopodes; *M*, position of mouth (×½); *c*, *Belinurus lacoëi* (×1); *d*, *Prestwichia danæ*; *e–f*, *Leaia tricarinata*, dorsal and side views (×½); *g*, *h*, *Estheria ortoni*, two left valves (×8).

Creek in Illinois, which have furnished so many of the typical non-marine animals, as well as plants, of this period. Fish, too, were abundant, especially small sharks, of which nearly 300 kinds have become known. Ganoids were common, but the older types of armored fishes had almost completely disappeared. It is still a matter of dispute as to how far these fishes continued to remain denizens of the rivers and to what extent they had permanently adapted themselves to the seas.

Land Animals

The land life was also markedly diversified. Insects resembling modern forms but of much more archaic character were common (Fig. 1422), cockroaches of the size of a man's finger being not infrequent. Huge dragon-flies, more primitive than modern types, existed, one at least having a spread of wing of nearly two and a half feet. Spiders and scorpions were fairly abundant at this

FIG. 1422. — A Carbonic insect of the order Protorthoptera (*Propleticus infernus*, $\times\frac{4}{5}$). Coal-measures of Illinois.

time, and myriapods (thousand-legs and centipedes), often of large size, were common. Some of these types are illustrated in the figures in Chapter XL.

But the most striking of the land forms were the amphibians of the group *Stegocephalia*, which had their heads covered with bony plates and their tooth-structure much complicated (Labyrinthodont type). These became more characteristic in the succeeding period, when reptiles also became a striking element of the land fauna. Their structure, rise and decline will be more fully discussed in another chapter (Chapter XL).

Plants

Because of the wide extent of continental strata, especially those inclosing coal beds, the flora of the Carbonic or Pennsylvanian is preserved *in extenso*, and often in wonderful perfection. Many of the plants found in these beds had their ancestry in the preceding era, or even in the Devonian, but at no previous time was the plant life of the land undergoing such great modification nor did it exist in such profusion as in the Carbonic or Pennsylvanian era.

Fig. 1423 *a*. — Carbonic fern, *Mariopteris pottsvillea*, Lower Pottsville. (After D. White.)

Fig. 1423 *b*. — Carbonic fern, *Pecopteris vestita*. Coal-measures, Pennsylvania. (After Lesquereux.)

Ferns. — The most typical of the plants include both true ferns and the more highly specialized seed-bearing forms which marked the first step (though probably a lateral one) towards the development of modern seed-bearing

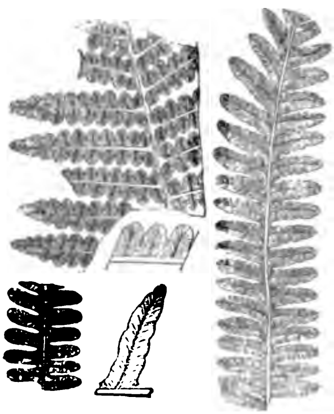


Fig. 1423 *c*. — A common Carbonic fern, *Alethopteris pennsylvanica*. (After Lesquereux.)

Fig. 1423 *d*. — *Neuropteris pocahontas*, Lower Pottsville. (After D. White.)

plants. The most typical of the fern-like types include: *a*. *Sphenopterid* types in which the pinnules are small and wedge-shaped (*Sphenopteris*, Fig. 1390 *a*, p. 473; *Mariopteris*, Fig. 1423 *a*); *b*. *Pecopterid* types in which the pinnules are more or less parallel-sided and affixed by a broad base (with branched

FIG. 1423 *e*. — Carbonic fern, *Neuropteris clarksoni*. (After Lesquereux.)

FIG. 1424 *a*. — *Annularia longifolia*. (After Lesquereux.)

FIG. 1424 *b*. — *Lepidodendron modulatum*, a portion of the bark, flattened.

FIG. 1424 *c*. — *Lepidodendron obtusum*, part of a fragment of flattened bark. (After Lesquereux.)

median veins) (*Pecopteris*, Fig. 1423 *b*), or become broadened and confluent, with a simple median vein (*Alethopteris*, Fig. 1423 *c*); *c*. *Neuropterid* types

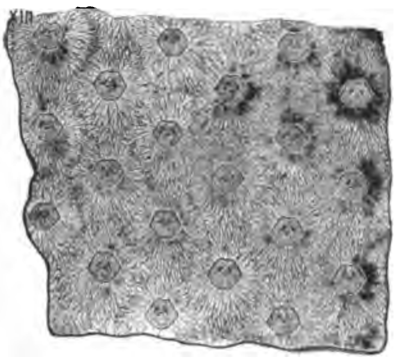


FIG. 1424 *d*. — *Sigillaria stellata*; part of bark flattened. Coal-measures. (After Lesquereux.)

FIG. 1424 *e*. — *Sigillaria potita*. Coal-measures.

in which the pinnules have a more or less heart-shaped base and generally strong median and forked lateral veins (*Neuropteris*, Fig. 1423 *d*, *e*).

Club Mosses or Lycopods. — These were represented by numerous species of *Lepidodendron* (Fig. 1424 *b*, *c*) and *Sigillaria* (Fig. 1424 *d*, *e*), and by their pros-

FIG. 1425 *a*. — Stem and root-stocks (Stigmaria) of a Sigillaria tree of the Coal-measures in the place where it grew, after removal of the enclosing sandstone layers. Victoria Park, Glasgow. (Photo by author.)

trate root-stocks, *Stigmaria* (Fig. 1425 *a*, *b*). The Equisetæ, or Horsetails, were represented by the tree-like *Calamites* (Fig. 804, p. 78), while a climbing form, *Sphenophyllum* (Fig. 806, p. 80), with wedge-shaped leaves in whorls, was also distinctive. The *Cordaites*, or early coniferous trees, already common in the Devonian, also abound in the Pennsylvanian, where their large strap-shaped leaves often characterize the deposits (Fig. 1426). (See further summary of Palæozoic life in Chapter XL.)

FIG. 1425 *b*. — Basal position of a large Sigillaria tree with widespreading root-stocks (Stigmaria) in the place where it grew in Carbonic time, after the removal of the inclosing sandstone layers. Victoria Park, Glasgow. (Photo by author.)

FIG. 1426. — *Cordaites lingulatus*, from the Coal-measures of Commentry, France. (About one-fourth natural size.) (After Haug.)

CHAPTER XXXVIII

THE PERMIAN OR PERMIC SYSTEM

BETWEEN the Coal-measures and the red Triassic sandstone (Bunter Sandstein) of northern Germany lies a series of red sandstones covered in turn by a magnesian limestone, which had long been known to the miners as the *Zechstein*, a name of somewhat doubtful origin, but believed by some to have originated from the tough character of the rock (German *zäh*), and by others to have originated from the fact that upon it rest the *Zechenhäuschen* or shaft-huts of the numerous small shafts which penetrate to the copper slate. At the base of this limestone series lies the important black copper-bearing shale, the *Kupferschiefer*, which rests upon the red sandstone, sometimes with an intervening white sandstone (*Weissliegendes*, an old dune sand). As the red sandstone marks the lower limit of productivity of the copper slates, it was designated by the miners as the *rotes totes Liegendes* (red dead basal series), a name which was later contracted into *Rothliegendes*.

The Zechstein further became of great economic importance by the discovery that it contained extensive salt deposits, which later proved to carry the valuable potash salts for which the formation has become famous.

Because of the marked twofold division of this group, the name *Dyas* was proposed for it by the Franco-American geologist Jules Marcou, and adopted by the German geologists generally, with Geinitz as the leader. In England this system is represented by the Magnesian Limestone of Durham, which passes westward into the lower New Red Sandstone.

It was at about this stage in the development of the knowledge of these formations that Murchison, then at the height of his fame for his discoveries in Siluria, made his extended journey in Russia in company with the French geologist De Verneuil and the Russian geologist Count Keyserling. On the western border of the Ural Mountains, especially in the Gouvernement of Perm, they found an extensive series of red marly and sandy strata with some limestones, which rested directly upon the upper Coal-measures and carried organic remains partly related to those of the underlying system and in part distinct from them. For this system, the essential equivalent of the German Dyas and of the English Magnesian Limestone, Murchison in 1841 proposed the name *Permian* (from the Russian Gouvernement of Perm), and this name was promptly adopted by geologists.

In eastern North America the Permian is of scant development, and the series of coal-bearing sandstones and shales which represent it (*Dunkard* series) was originally united with the underlying Carbonic formations, and is called Permo-Carboniferous. The extended studies of the upper Palæozoic rocks of Kansas by Prosser and others, and of the great limestones of the southwest (*Guadaloupian* series) by Girty and others, has shown that the Permian system is well developed in western and southern North America. Recent studies in Idaho, Wyoming, and Utah have shown that rocks of this age carry important deposits of phosphate of lime, while in Kansas enormous beds of rock-salt are found to form a part of the Permian. This system has become well established, though some American as well as European geologists unite it with the Carbonic and Mississippian formations into the *Anthracolithic system.*

As the Permian system is most completely and typically developed in Europe, and because it has been more thoroughly studied there than elsewhere, we shall consider its development in that continent first.

The Permian of Europe

It will be remembered that the close of the Carbonic witnessed the pronounced folding of the beds of that system and the addition of these folds to the mountain ranges which divided Europe into a northern and a southern basin (Fig. 1427). The Armorican chain on the west and the Variscian chain on the east constituted the most pronounced topographic elements of these systems. Even during the Carbonic, as we have seen, the northern basin was distinct and subjected to a gradual emergence by the withdrawal of the sea eastward, while over the emerged region coal swamps came into existence and continental sedimentation prevailed. With the opening of Permian time these continental sediments continued to form, but because of the greater elevation of the bounding mountain chains, which then shut out the moisture-bearing winds, the formation of coal-swamps had come to an end, and the climate of this basin became more and more arid. As a result the vegetation finally became very scant, except probably in the higher regions of the mountains and on their windward slopes, where the early coniferous trees flourished and developed new genera and

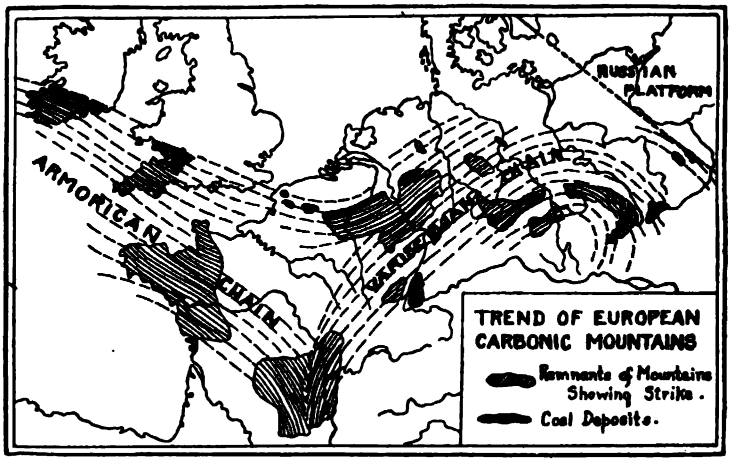


FIG. 1427. — Outline map of western Europe, showing the trends of the Armorican and Variscian mountain chains of late Palæozoic time. The areas in which these older folded Palæozoic rocks appear to-day are shaded, the lines indicating the strike of the strata. Areas where coal deposits are found are shown in black. (Modified from Kayser.)

species. The lower slopes of the mountains on the northern or leeward side, however, probably became barren of vegetation, and there rapid disintegration of the rocks was taking place. This disintegration furnished sands and finer rock material which, remaining exposed for long periods of time, had its disseminated iron thoroughly oxidized by the air which filled the spaces between the particles, there being little or no water to occupy these spaces as is the case in regions of a moister climate. At infrequent intervals heavy rains in the mountains caused torrents of water to rush down their bare northern slopes, and these washed away much of the disintegrated and thoroughly oxidized material which finally came to rest in the bottom of the mountain-enclosed basin. There this material accumulated as river-laid and sometimes wind-modified deposits of sand and mud of considerable thickness.

Long after, when these beds were buried by younger deposits and underwent a process of aging within the crust of the earth, their color, at the time of deposition probably a light yellow or ochery tint, changed to red, as bricks molded from yellow clay change to red on burning, this process driving off the water originally combined with the iron oxide and changing that oxide to the anhydrous state in which its color is red (hematite). That is why these older Permian beds of northern Europe, especially those of England, northern France, and Germany, are now mainly red sandstone and, as they form the basal part (German, *Liegendes*) of the Permian deposits of that region, they have become familiarly known as the *Rothliegendes*, which means red basal series. These deposits are now found over most of the basin, *i.e.*, in England, northern France, and Germany, while within the chains of the Armorican and Variscian mountains, that is, in the intermontane valleys and even on the eastern and northeastern slopes of the Variscian chain, such intermontane deposits formed the older Permian red beds of the regions which now constitute the border of the central plateau of France.[1]

The Rothliegendes is divisible into a lower series ranging in thickness up to 400 meters or more, and an upper series reaching in places a thickness of 500 meters. Its distribution ranges from Commentry in France, to Silesia on the one hand, and to western England on the other. They form the older red beds of the Vosges Mountains and the other horsts of this type (Fig. 1428), and in the dry moat of the ancient Heidelberg castle on the Rhine they can be seen to lie directly upon the granite.

In many sections where moisture still prevailed at the beginning of the period, coal beds were formed and now constitute a part of the lower Rothliegendes. But in all cases the higher beds are free from coal and are of a red color. In western England these continental beds are without coal, about 3000 feet thick, and mostly

[1] These Permian red beds must not be confused with the younger Triassic red beds which nearly everywhere overlie them in this region, and which can be distinguished chiefly by the few fossils which they contain except where calcareous or other beds separate the two series.

red in color. Frequently beds of more or less angular fragments (brecciated beds) of older rocks, derived partly from the Scottish uplands and partly from other sources, are inclosed in the series. In eastern England, however, the series is only a few hundred feet thick, and is generally indistinguishable from the New Red Sandstone, which is of Triassic age.

While these sands were being spread over the dry basin of northern Europe and the valley-bottoms within the mountains, often inclosing trunks and branches of the coniferous trees which fringed

FIG. 1428. — Middle Permian sandstone, showing torrential stratification. Champenay, Alsace. (After Haug.)

the mountain tops and which were washed down during exceptionally violent floods, the sea still lingered in eastern Europe where the Ural mountain chain had begun to rise, and it also lingered in the Mediterranean basin to the south of the Palæozoic mountain chain.

The deposits which were forming along the western flanks of the rising Ural Mountains in Russia consist of an alternation of sandstones, often variously colored, and of limestones and shales. The sandstones are chiefly continental deposits and represent the extensive wash of detritus from the mountains. They inclose the remains of land animals and of plants similar to those found farther west. The limestones contain marine fossils which are still closely related to those found in the underlying Carbonic strata. These deposits form the *Artinskian* series, and they are succeeded by other marine limestones and by dolomites (*Kungurian* series), which show that the sea continued to linger in this region while the red beds were forming in the basin farther west. But the influence of the withdrawing sea was felt even here, for these marine beds are succeeded by red beds and by other strata with freshwater mollusks and plant remains, but with occasional marine layers intercalated in the series, so that it is clear that the sea was still present in the neighborhood. It was this sea which, during a temporary reëxpansion, entered the North European basin and formed the Zechstein formation with its salt deposits, as we shall see presently.

In the Mediterranean basin, which included the region now dominated by the modern Alps which were then non-existent, marine waters also persisted throughout Permian time. But along the northern border of this southern basin, which was in part formed by the southern and eastern slopes of the Variscian mountain chain, waste from the mountain slopes accumulated, in part forming alluvial fans above sea-level, though the margins of these fans extended into the sea. Wherever the sweep of those ancient Alpine Mountains (which, it must be remembered, lay north of the present Alps) formed a protected embayment, from which the moisture-bearing winds, coming chiefly from the west or southwest, were excluded by the height of these mountains, the sands of the alluvial fans were oxidized and as a result are to-day red beds. They are now seen as red sandstones and conglomerates in Switzerland and northern Italy, and sometimes reach a thickness of 900 meters. After their deposition they were covered by the advancing waters of the Mediterranean and great beds of marine limestone were deposited (*Bellerophon limestone*). All of these beds were later folded and broken by the disturbances which created the modern Alps out of a low-lying sea-margin or sea-bottom country, and erosion since the birth of the Swiss and Italian Alps has again removed a considerable portion of these rocks, so that to-day we find only scattered remnants of them. But that this was once a great continuous series admits of no doubt.

Probably the most important event of Permian time in Europe was the transgression of the sea in the second or middle period of the Permian, which is indicated by the presence of the marine limestones above the red beds of southern Europe. It was an echo of this transgression which caused the Russian Sea to extend westward and fill the North European desert basin with marine waters. Such an event would occur to-day were the modern Mediterranean Sea to rise and flood the Sahara desert. This advent of the sea in northern Europe was a slow one, for it first entered the old and mostly dry river channels which dissected the sands of the desert basin. This is shown by the fact that at first the marine beds have a very sporadic and limited distribution, instead of covering the whole area as a continuous sheet, while in many places dune sands formed the margins of the old river channels. In some of these old deeper-lying regions between the dunes, regarded as the old river channels, there is another very remarkable deposit. This is a black mud-rock, never more than a few feet

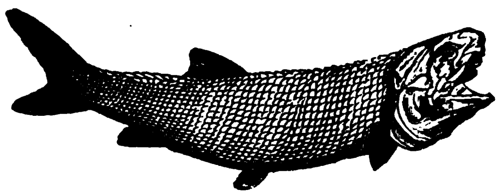


FIG. 1429. — *Palæoniscus freieslebeni* (×½), an Upper Permian (Zechstein) fish. (After Kayser.)

thick, but filled with the flattened and often beautifully preserved bodies of fish (*Palæoniscus freieslebeni*, Fig. 1429; and *Platysomus*, Fig. 1430) and plant remains (*Ullmannia*, Fig. 1431), and occasionally the bones of saurians. Moreover, this black mud is rich in minute grains of copper sulphide, so much so that the deposit, in spite of its thinness, has been an important source of German copper for many centuries. Its productivity may be judged from the fact that from 1904 to 1906 it yielded from 18,000 to 20,000 metric tons of copper per annum, or about 5/7 of the total copper production of Germany for that period. During the recent war it has of course been of even greater importance, but figures as to the quantity of copper obtained from it are not available.

What, then, is the origin of this remarkable deposit, which lies directly upon the old desert sands, the red beds, and is covered by marine limestones, the Zechstein? The most reasonable explanation seems to be that the muds and copper salts were brought by the rivers from the uplands, and that these regions constituted lagoons and estuaries which had come into existence with the revival of river activity as the climate of the region became moister, probably because of the widespread transgression of the sea. The fish in all probability were inhabitants of the rivers, and as the first inundation of the salt sea reached this district they were destroyed by millions, not having become as yet adapted to life in the salt water. It may be that at first the salt water entered these lagoons only at intervals, long enough to cause the death of the fish, and that then the basins remained as stagnant pools in which the decaying fish bodies formed conditions for chemical reactions, which caused the precipitation of the copper salts originally held in solution in these waters, the sulphur probably being obtained from the sulphates in the sea-water. This process was similar to the formation of iron sulphide along the mud-flats of the modern seacoast, where decaying organic matter and bacterial activities favor such chemical reactions.

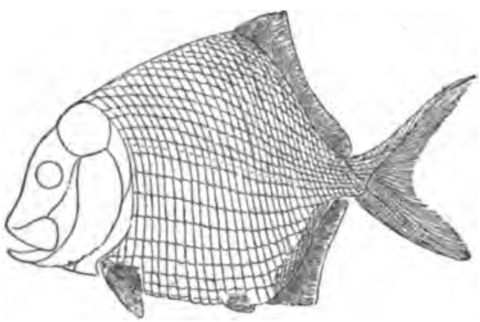


FIG. 1430. — *Platysomus gibbosus* (×½), an Upper Permian (Zechstein) fish. (After Kayser.)

FIG. 1431. — *Ullmannia phalaroides*, an Upper Permian (Zechstein) conifer. (After Kayser.)

With continued transgression the sea finally filled the north European basin, extending as far west as eastern England, where the Magnesian Limestone preserves the record of its presence and of its life (Fig. 1432). In western England, however, sands continued to be deposited, and this was true also to some extent in northern France. Hence in these regions the marine limestones are replaced by continental or estuarine beds, still red in large part and showing that in spite of the transgressing sea aridity continued to prevail in the western part of the basin.

layer which protected them from re-solution when the sea once more flooded this basin. Again, however, the free supply of sea-water was cut off and evaporation recommenced, so that a second series of anhydrite deposits was formed, followed again by rock-salt and finally by the more soluble potash and other salts. With this second flooding of the basin the marine organisms again entered it, but were once more killed as the water became dense by evaporation. Hence we find that this entire series of deposits contains fossiliferous horizons only at the base of the series, and between the two salt series. After the second evaporation period the basin remained for a long time the site of continental deposits, these forming the Lower Triassic series (Bunter Sandstein) of the early Mesozoic.

The Permian of North America

Eastern North America still remained the site of continental sedimentation in Permian time, but it appears that the region continued to be subjected to the moist climatic conditions which prevailed in Pennsylvanian time, so that the Permian deposits (*Dunkard series*) are essentially similar to those of the underlying Pennsylvanian, inclosing many coal seams, most of them very thin and unimportant. In the Kansas basin east of the Rocky Mountain protaxis the marine conditions which existed in Pennsylvanian time also continued into the Permian, so that the deposits and marine faunas of the later period do not differ essentially from the older ones. In this respect they correspond to the older Permian deposits of Russia, and their Permian age is recognized only by the plant remains which characterize the coal beds of the continental deposits with which the marine strata continued to be intercalated for a time. Along the western side of this basin, however, red beds represent this series, and these probably were oxidized sands deposited in more or less enclosed intermontane basins, into which the sea entered only occasionally. When it did so, it left gypsum as a precipitation product; but salt does not appear to have been deposited in these districts.

Marine conditions did not continue throughout Permian time in the Kansas basin, but during the later part of this period its former southern connection with the Cordilleran Sea on the west was interrupted. In the basin thus isolated great salt deposits were formed, in places as much as 600 feet thick, and at first sight it would appear that we have here a series analogous to that of northern Europe and that here, as there, potash salts should be

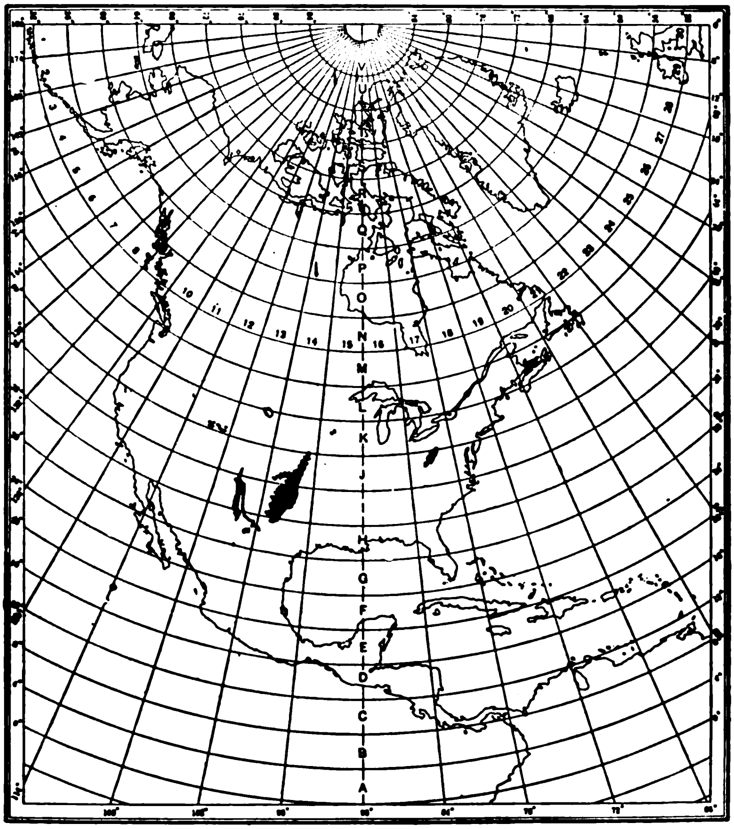


FIG. 1435. — Map showing the outcrops of the Permian rocks in North America. (After Bailey Willis.)

found, at least locally. This apparent similarity is, however, destroyed by the fact that there seems to be no great continuous gypsum or anhydrite series beneath the salt deposits such as is found in Germany and such as should underlie all normal salt deposits formed by evaporating sea-water (see Pt. I, p. 234). The absence of such sulphate beds seems to indicate that the Kansas salt beds are of desert origin, *i.e.*, deposits of salt derived from connate waters, and that hence potash salts are not to be expected. None have as yet been found, but it may be that further exploration will reveal the presence of gypsum beds beneath some portions of the salt and so render more hopeful the exploration for potash deposits. The salt series, as well as the marine beds where the salt is absent, are covered by red beds which appear to have been spread over this region by sand-bearing streams from highlands which existed on the southeast (Oklahoma, etc., see map, Fig. 1436).

Throughout the Cordilleran geosyncline, on the other hand, marine conditions apparently prevailed during much of Permian time, for here we have extensive deposits of marine sediments, partly limestones, which represent this system. Much terrigenous material was also carried into this trough, partly by streams from the Rocky Mountain land mass, and some of these terrigenous deposits accumulated above sea-level. An important feature of these western Permian sediments is the presence in them in Idaho, Wyoming, and Utah of phosphate beds, sometimes of great thickness. The origin of these deposits is not as yet well understood.

Finally, we must note a remarkable series of beds referred to the Permian, which is found in the Trans-Pecos region of Texas and in New Mexico. Here beds of undoubted Pennsylvanian age (*Hueco* formation) are succeeded by sandstones in the northern and more generally by limestones in the southern region, these constituting the *Delaware Mountain* series which has a thickness of over 2000 feet. Above this series lie about 1800 feet of limestones (*Capitan limestone*) and these two series form the *Guadaloupian group*. This is followed by several thousand feet of sandstones with some limestones, and these in turn by red beds, often with extensive gypsum deposits.

The fossils found in the Guadaloupian series are, on the whole, quite distinct from any that are known elsewhere in the American Permian, though some of the types have been found in beds involved in folds of the Klamath Mountains of California. They have a number of forms in common with the Permian beds of India and parts of the Mediterranean basin. As these beds seem to grade laterally into shore deposits or into lagoonal sediments (gypsum beds) when traced northward, it would appear as if they were formed in a Pacific embayment which lay to the south of the

Kansas and main Cordilleran basins, and which was practically separated from them (Fig. 1436). This would account for the

FIG. 1436. — Palæogeographic map of North America, showing the probable distribution of land and water (black) in Permian time. (Original.)

distinctness of the fauna. The relationship is as yet, however, only partly understood. It is not impossible that the Guadaloupian beds are the marine strata deposited during the period of salt formation (undoubtedly a long period) in the Kansas basin, for this salt lies between the fossiliferous beds of that region and the red beds (*Cimarron* series) which follow. If that is the case, the possibility that the salts of Kansas are lagoonal deposits from sea-water looms up strongly.

The Permian of Asia

In northwestern India (Salt Range) a very extensive series of strata represents the deposits of Permian time. They begin with an old glacial tillite, 10 to 40 meters in thickness, which rests unconformably upon Cambrian beds. This is followed by an alternating series of marine and continental beds (200 meters), above which lie limestones characterized by various species of the brachiopod *Productus* (*Productus limestone*), with a maximum thickness of 266 meters, and this is followed by beds of Lower Triassic age, probably with a break in sedimentation between the two. It has, however, been held that the lower and middle *Productus* limestones are of Pennsylvanian age, while the upper *Productus* limestone (100 meters) is of the age of the Lower Permian (Artinskian) of Russia. This would imply a considerable hiatus between this series and the overlying Triassic, and would place the glacial tillite in the Lower Pennsylvanian or in the Mississippian. The problem evidently requires further study.

Permian deposits are also known from Armenia, Persia, Tibet, Yunnan, Nanking, Timor, and elsewhere in South Asia, but they have been only partly investigated.

The Glacial Deposits of Permian Age

We have noted that the Permian of India begins with an old tillite or consolidated glacial deposit with scratched and polished boulders and pebbles which rests upon the Cambrian beds, and is succeeded by sands and clays apparently of fluvio-glacial origin and later by marine sands and the *Productus* limestone. In the interior of the Indian peninsula a similar tillite, but ranging to 600 meters or more in thickness (*Talchir conglomerate*), forms the base of a great series of continental deposits, the upper part of which is of Mesozoic age. The tillite rests upon a striated and polished surface of older rock similar in all respects to the striated rock surfaces found beneath our latest still unconsolidated glacial deposits. The movement of the ice in this region seems to have been from the south northward, or away from the equatorial region of to-day. Above the tillite follows a series of sandy beds, and higher still, sandy and conglomeratic strata with some coal beds and plant remains, chief among which are the remarkable fern-like types *Glossopteris* (Fig. 1437) and *Gangamopteris*. Above this follow beds referred to the Triassic.

FIG. 1437. — *Glossopteris browniana*. Permian, New South Wales, a single frond, one-third natural size. (After Steinmann.)

A second series of glacial deposits belonging to this era is found in South Africa (Cape Land, Transvaal, Rhodesia, extending to Nyassa land). This is the so-called *Dwyka conglomerate*, which rests upon folded and eroded older rocks, the surface of which also shows polishing and striation of the glacial type (Fig. 1438). The Dwyka tillite ranges up to 350 meters in thickness, and represents a record of extensive glaciation. From the character and original home of the rock fragments inclosed in it, it appears that the glacial movement in this region was southward, that is, from the region of the present equator toward the present South Pole. Intercalated in the tillite are bedded sands and conglomerates such as are found in the till of the last glacial period, and which were formed by intermittent glacial waters. Immediately above the Dwyka tillite follow sandstones and shales (*Ekka* beds) with the characteristic plants *Glossopteris* and *Gangamopteris*, with *Neuropteris* and *Sigillaria*, and with remains of amphibia and reptiles. The beds succeeding these deposits are generally referred to the Triassic. The whole series of continental sediments is called the *Karoo* formation.

A third occurrence of Permian glacial deposits is found in Australia (Victoria, New South Wales, and Queensland) and in Tasmania and New Zealand. In Victoria the basal tillite rests unconformably upon Mississippian or older beds and has a thickness exceeding 400 meters in places. This tillite, too, contains scratched and polished boulders and pebbles. It is followed by coal-bearing sandstones, in which *Glossopteris* and *Gangamopteris* again occur. In Queensland, and especially in New South Wales, the series which follows upon the Mississippian strata consists of coal-bearing non-marine beds, with the remains of the *Glossopteris* flora and with many marine intercalations which contain *Productus*, *Spirifer*, and other brachiopods, and include polished and striated glacial pebbles. This marine series sometimes reaches a thickness of 1200 meters, and is followed by the *Newcastle coal* series (300 to 500 meters thick) in which the flora already shows

FIG. 1438. — Section of the Dwyka boulder-clay at Prieska, northwestern part of Cape Colony, Africa. (After Hatch and Corstorphine, *Geology of South Africa.*)

Mesozoic affinities. The transportation of the glacial deposits in South Australia appears to have been from south to north.

Ancient glacial deposits of this type are known from Brazil (Rio Grande do Sul, See Fig. 360 *a*, p. 435, Pt. I, glacial pebble, Brazil). Here, too, they are followed by coal-bearing sandstones with the *Glossopteris* flora. In Argentine these *Glossopteris* beds rest directly and unconformably upon older Palæozoic or pre-Palæozoic rocks and are covered by sandstones of Triassic age.

The difficulty in the interpretation of these glacial deposits lies in their position partly within the modern equatorial belt, and the evidence shown in India on the north and in South Africa on the south of the movement of the ice away from the equator. In Australia, where the movement was toward the equator, the glacial deposits were evidently formed close to sea-level or beneath it, unless the glacial pebbles represent a secondary inclusion in marine deposits. Among the explanations which have been offered are, first, the universal lowering of the temperature of the whole earth at this time, so that ice could accumulate even in the equatorial regions and, second, a different position of the earth's axis at that time, so that one of the poles came to lie within the Indian Ocean near to the present equator. Both explanations meet, however, with great difficulties and the problem must be considered as still far from being solved. Other explanations have been offered, such as change in ocean currents, change in winds due to the formation of new mountains, etc., but all of these have been shown to be inadequate causes to produce such extensive glaciation (Davis).[1]

It should be noted that the positive evidence of glaciation in late Palæozoic time was restricted to the southern hemisphere, except in the case of India. There are, however, in North America boulder beds which have been regarded as of glacial origin (Boston and Narragansett basins), and scratched pebbles have been reported from regions still farther north (Prince Edward Island). Boulder beds, possibly of glacial origin, are known from England as well. None of these are, however, positively recognized as true glacial deposits.

General Characteristics of the Permian Fauna and Flora

Marine and River Faunas

The marine animals of Permian time were not very different from those of the preceding Carbonic era. The *Fusulina* types of **Foraminifera** continue, and a few **corals** still occur (especially in India). **Bryozoa** (*Fenestella*, *Polypora*, *Phyllopora*, *Acanthocladia* (Figs. 1439, 1440) are abundant and often reef-forming. *Productus* is the most typical among the **brachiopods**, especially common being the long-spined *P. horridus* (Fig. 1433). There are also several related genera, *Aulosteges*, *Strophalosia*, *Oldhamia*, etc. (Figs. 1441–1443),

[1] The late Professor Koken reconstructed a map of Permian geography in which he placed the South Pole in the Indian Ocean (long. 80° E., lat. 20° S. and the North Pole in Mexico, long. 100° W., lat. 20° N.). This is confessedly only an attempt to explain the glacial conditions on the hypothesis of polar displacement and must not be taken as fully accepted even by its author.

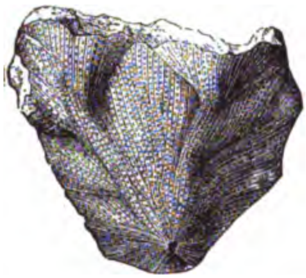


FIG. 1439. — *Fenestella retiformis*, an Upper Permian (Zechstein) bryozoan. (After Kayser.)

FIG. 1440. — *Acanthocladia anceps*, an Upper Permian (Zechstein) bryozoan. (After Kayser.)

FIG. 1441. — *Aulosteges gigas*, a European and Asiatic Permian brachiopod. (After Kayser.)

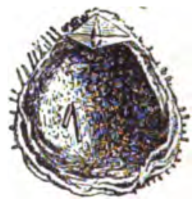


FIG. 1442. — *Strophalosia goldfussi*, a characteristic Permian brachiopod of Europe. (After Kayser.)

a *b*

FIG. 1443. — *a*, *b*, *Oldhamia decipiens*, an aberrant form of brachiopod: (*a*, internal view of the ventral valve; *b*, median septum of the dorsal valve with lateral septa). *Productus* limestone, Permian, Salt Range of India. (After Haug.)

which are most characteristic of the Permian. Especially typical of the Mediterranean, Indian, and southwest American (Guadaloupian) Permian are certain brachiopods, which from being permanently attached have suffered a grotesque distortion in growth until they resemble corals more than brachio-

a *b*

FIG. 1444. — *Richthofenia lawrenciana*, a brachiopod of aberrant growth; *a*, exterior; *b*, section of the larger valve (×½). *Productus* limestone, Permian, Salt Range of India. (After Waagen.)

FIG. 1445. — *Tegulifera deformis*, a Permian brachiopod of aberrant growth. (After Kayser.)

pods (*Richthofenia*, Fig. 1444; *Tegulifera*, Fig. 1445). Among **pelecypods** the genera *Gervilleia*, *Myalina* (Figs. 1446, 1447) and *Pseudomonotis* (Figs. 1448 *a*, *b*) are most characteristic, and among **gastropods** *Bellerophon* and some others (Figs. 1449, 1450). These mollusks are not very different in character from the Carbonic types. The **cephalopods**, too, are partly like those of the Carbonic, but in addition there are a number of ammonoids

FIG. 1446. — *Gervilleia ceratophaga*, an Upper Permian (Zechstein) pelecypod. (After Kayser.)

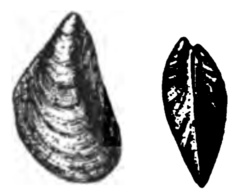


FIG. 1447. — *Myalina hausmanni*, an Upper Permian (Zechstein) pelecypod. (After Kayser.)

which show marked advance in development over the Carbonic goniatites, having ceratitic or even ammonitic sutures (*Waagenoceras*, *Medlicottia*, Fig. 1451; *Cyclolobus*, Fig. 1452; *Popanoceras*, Fig. 1453, etc.). The Carbonic genera of **trilobites** persist into the Permian, and then the race dies out completely. **Echinoderms** are rare.

Fishes appear still to be most abundant in the rivers, for their remains are

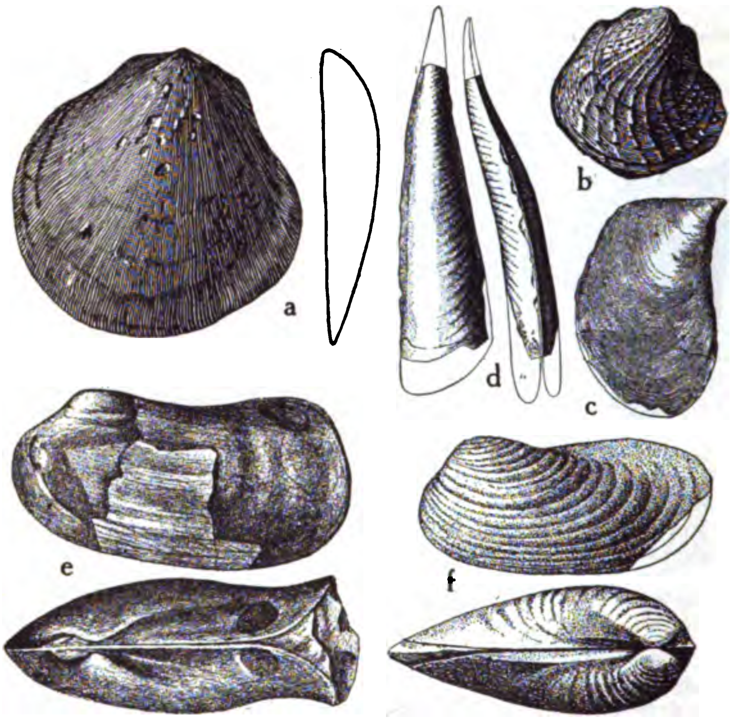


FIG. 1448. — Permo-Carbonic pelecypods of North America. *a*, ***Pseudomonotis kansasensis*** with section ($\times\frac{2}{3}$), Carbonic and Permian, Colorado, Kansas; *b*, ***Pseudomonotis hawni*** ($\times\frac{2}{3}$), Carbonic and Permian, Colorado, and Kansas; *c*, ***Myalina subquadrata***, right valve ($\times\frac{1}{2}$), Carbonic, Colorado, and Permian, Kansas; *d*, ***Aviculopinna peracuta***, right and dorsal views ($\times\frac{1}{2}$), Carbonic of North America, Permian, Kansas; *e*, ***Chænomya leavenworthensis***, left and dorsal views ($\times\frac{2}{3}$), Carbonic, Illinois, Iowa, Colorado, etc., Permian, Kansas; *f*, ***Allorisma terminale***, left and dorsal views ($\times\frac{2}{3}$), Carbonic throughout the United States, Permian, Kansas.

FIG. 1449.—***Euomphalus catilloides***. Permian of the central United States. (Occurs also in Coal-measures.) (I. F.)

FIG. 1450.—***Sphærodoma intercalare***, Permian of Nebraska. (Occurs also in the Coal-measures of the eastern United States.) (I. F.)

chiefly found in deposits of fluvial origin. There may, however, have been marine types as well. Most of them were ganoids. The two most typical

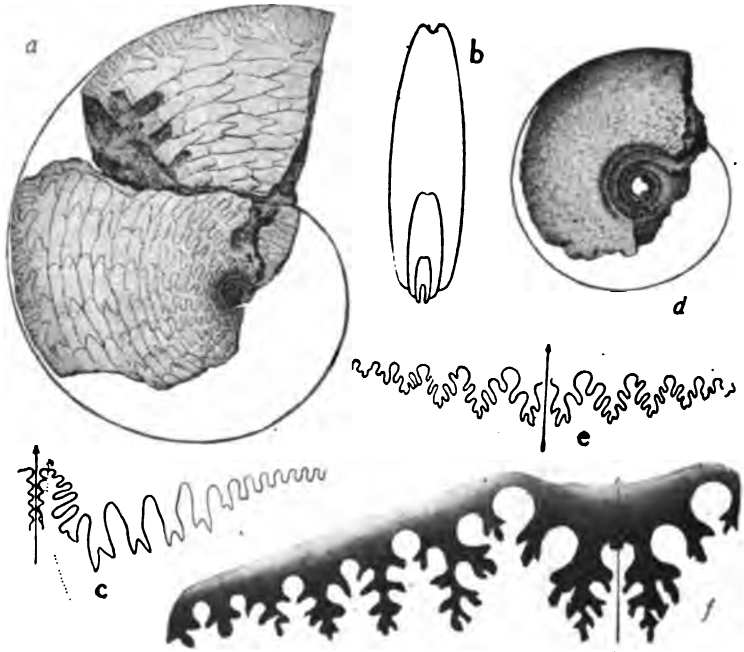


FIG. 1451. — Permian ammonites. *a-c*, *Medlicottia copii; d-e*, *Waagenoceras cumminsi; f*, *W. hilli*, suture. (After J. P. Smith from I. F.)

genera found in the north European Permian have already been referred to (p. 512). Several sharks also occur.

FIG. 1452. — *Cyclolobus stachii* (×$\frac{5}{8}$), a Russian and Asiatic Permian ammonite. (After Kayser.)

FIG. 1453. — *Popanoceras multistriatum* (×$\frac{8}{9}$), a Russian and Asiatic Permian ammonite. (After Kayser.)

Fig. 1454. — *Walchia piniformis*, a characteristic Lower Permian conifer. Part of stem and leaves, natural size (Rothliegendes, Europe). (After Steinmann.)

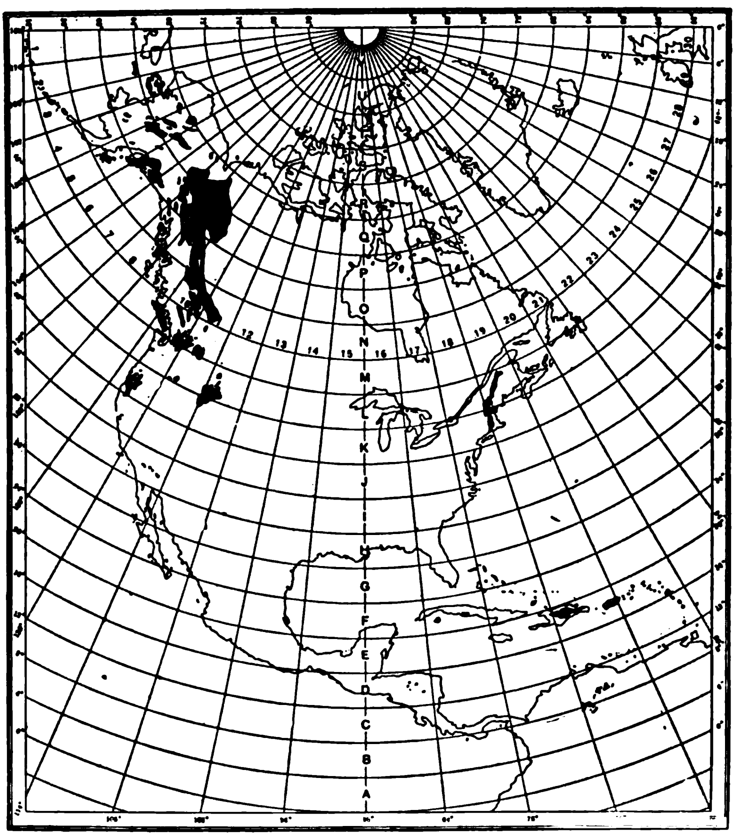


Fig. 1455. — Map showing the outcrops of Palæozoic rocks, the exact horizons of which have not yet been determined. (After Bailey Willis.)

Land Animals

Here belong the **insects**, of which a considerable number is known (Fig. 1533); and the **myriapods**. The land vertebrates are, however, the most characteristic. The *Stegocephalians* (Labyrinthodonts) lead among the **amphibia**, while the **reptiles** were represented by the *Rhynchocephalians* and *Theromorphs*. These will be more fully discussed in a subsequent chapter.

The Land Flora

The flora of the Permian lands was quite sharply divided into a northern and a southern type, though the latter also encroached upon the northern hemisphere. The northern type is a derivative from the Pennsylvanian (Carbonic) flora and consists of **ferns** (*Sphenopteris*, *Callipteris*, Fig. 812, p. 83), **calamites** and **conifers** (*Walchia*, Fig. 1454, *Ullmannia*, Fig. 1431). **Sigillarias** and **Lepidodendrons**, with their *Stigmaria* root-stocks, have disappeared. The southern flora is dominated by the great ferns *Glossopteris* (Fig. 1437) and *Gangamopteris*. It is sometimes spoken of as the Gondwana flora because it is believed to have arisen on Gondwana Land, a hypothetical land-mass which is thought to have united Africa, India, and Australia in Palæozoic and early Mesozoic time, and which by some is carried across the South Atlantic to South America. The existence of this land-mass is postulated mainly upon the wide distribution of the *Glossopteris* flora.

CHAPTER XXXIX

CLOSING EVENTS OF PALÆOZOIC TIME

Progress of Deposition in the Appalachian Geosyncline. — We have seen that during Palæozoic time there was a progressive, though intermittent, rise of the land-mass of Appalachia, with a corresponding sinking of the Appalachian geosyncline, until many thousands of feet of clastic and organic strata had accumulated in this trough, the former being derived from the erosion of the Appalachian land-mass. Sometimes the rise of the oldland was very slow, at other times it rose more rapidly so that it became of sufficient height to shut out the moisture-bearing winds, which at that time were from the east. Then arid conditions prevailed and oxidized alluvial sands and muds, now represented by red beds, were deposited. Then again erosion lowered the mountainous land-mass sufficiently to enable the moist winds once more to invade the interior region, and deposits formed during more pluvial or rainy conditions accumulated, the last of these being the Pennsylvanian and Permian coal-bearing strata of eastern North America. The abundant and widespread swampy conditions which are indicated by the coal-beds are eloquent of a moist and perhaps semitropical climate at that period. Beginning with the bottom of the Appalachian Palæozoic, there are at least four important red bed series, each one of which indicates more or less semiarid conditions at the time of formation. These are: the *Juniata-Queenston* of the Ordovician, the *Longwood-Vernon* of the Silurian, the *Catskill* of the Devonian and the *Mauch Chunk* of the Mississippian. Each one of these, except the Silurian, forms the closing deposit of the system to which it belongs. The Longwood, on the other hand, forms the middle division of the Silurian.

Formation of the Appalachian Mountains. — The culminating event of these rising movements of the oldland and the depression of the geosyncline was a compressive movement which resulted in the folding of the strata of the geosyncline into a series of asymmetric anticlines and synclines, together with a number of thrust-faults, which carried older beds over those of younger age. The anticlines almost invariably have a steep, nearly vertical, or even

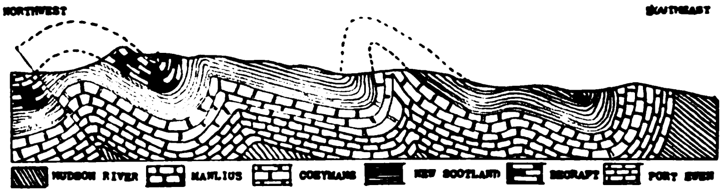


FIG. 1456. — Section across part of Becraft Mountain, near Hudson, New York, showing the Appalachian type of folding and overthrust. The strata involved are of Lower Devonian and Upper Silurian age (Manlius). The latter rests unconformably upon the Hudson River beds. (After Grabau, *Geology of Becraft Mountain.*)

overturned western and a more gently inclined eastern limb (Fig. 1456) and this is taken as indicative of a compressive movement from the east. In other words, the Appalachian land-mass moved towards the lowland on the west and crumpled the strata of the geosyncline between them. This direction of movement is also indicated by the thrust-faults in which the displacement of the overthrust masses is from the east westward or northwestward (Figs. 1457–1459). The general trend of the old trough and of the resulting folds was northeastward in the principal areas, though with a regular series of undulations. In the southern United States, however, where the trend of the old geosyncline was more nearly east and west, the compression seems to have proceeded from the south and the steep limbs of the anticline are in general on the north (Arkansas, Oklahoma), but in Texas the

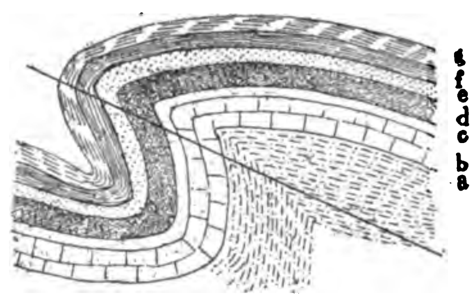


FIG. 1457. — Slightly overturned fold of the Appalachian type in the Hudson Valley near Albany. (*a*, Cambrian strata; *b*, Beekmantown; *c*, lower Trenton limestone; *d*, Normanskill shales; *e*, middle and upper Trenton shales; *f*, Utica shale; *g*, Lorraine beds.) (After Ruedemann.)

trend again bends southward. The general outline of these systems of trends is shown in the map (Fig. 1460).

Formations of the Post-Appalachian Geosyncline. — With the folding of this vast series of strata, the partial collapse of the oldland of Appalachia seems to have gone hand in hand, or this collapse may have followed the compression. As a result a new geosyncline came into existence upon the oldland to the east of the Appalachian geosyncline, and in this new trough the Mesozoic strata of the eastern and southern regions were deposited. This geosyncline will, therefore, be more fully considered in the discussion of the later formations. So far as a source of supply of clastic material is concerned, Appalachia virtually became extinct, and with this extinction by subsidence new physical and climatic conditions came into existence, most notable among which appears to have been the change in direction of the prevailing winds from easterly to westerly over the greater part of the United States, a direction which they still maintain at the present time.

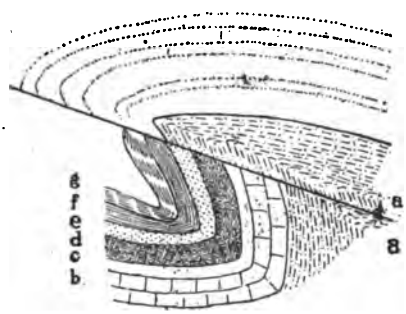


FIG. 1458. — Overthrust fault developed in the strata shown in Fig. 1457, near Albany, N. Y. (After Ruedemann.)

Formation of Domes and Basins. — The compressive force appears to have further manifested itself in the formation of the domes and basins of the eastern half of the United States. To be sure, these domes and basins had for the most part come into existence at earlier times, but their final elevation dates from the period of folding of the Appalachians. It may be that the earlier uplifts of the domes and the depressions of the basins were in all cases connected with earlier periods of folding, for we know that such folding occurred at the end of the Ordovician time (Taconic

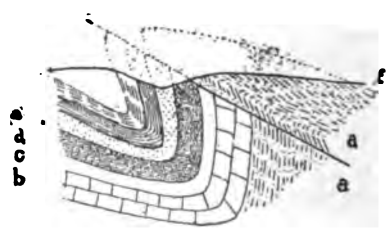


FIG. 1459. — Section near Albany showing the conditions to-day after prolonged erosion. (After Ruedemann.)

revolution) and during the Devonian. There may have been other periods of folding, the effects of which are not now seen because the strata folded at that time may have been removed entirely by erosion.

In general the relationship of the low domes and shallow basins of the interior to the Appalachian folds is such as to suggest that they are the product of the same compressive forces, the domings being merely the upward undulation of the distant strata under the influence of compression from three directions, while the basins represent the corresponding downward undulations.

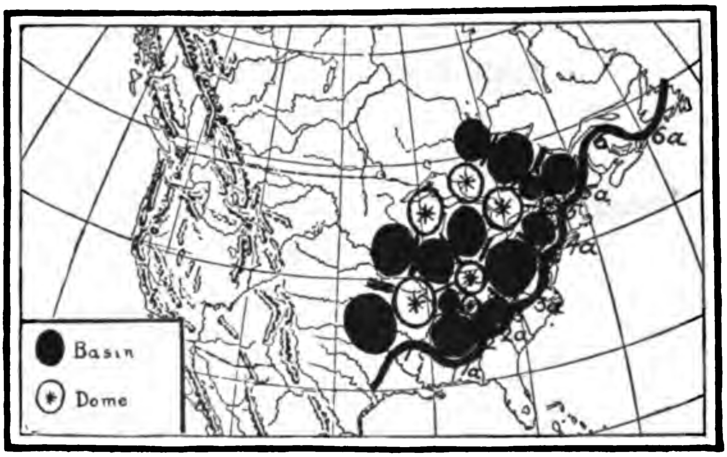


FIG. 1460. — Map showing the trend of the Appalachian folds in eastern North America and the distribution of domes and basins completed during the period of Appalachian folding.

Formations of the Palæocordilleran Ranges. — The deposits of the western or Palæocordilleran trough or geosyncline suffered folding probably at the same time as did those of the Appalachian region. Very little is as yet known of the Palæozoic folds of this region, because the subsequent disturbances developed a block-mountain topography by faulting and the trend of the fault-blocks differs from that of the older folds. But it is known that the series strikes northwestward in Arizona and New Mexico and then assumes a more northerly strike through the Great Basin region. It probably terminated in the Pacific west of the end of the international boundary line.

These folds, too, were asymmetric with the steep limb of the anticline on the east, so far as known, indicating a direction of pressure from the oldland on the west. In other words, it seems that North America was compressed from the east, the south, and the west, and that within this compressed area were formed the domes and basins, and around the margins the asymmetric folds.

Formation of the Cordilleran Geosyncline. — Coincident with the folding of the Palæocordilleran chain, or shortly after, the oldland on the west, which had furnished the material for the deposits in the trough, collapsed and upon its surface a new geosyncline was formed, in general parallel to but west of the older one which

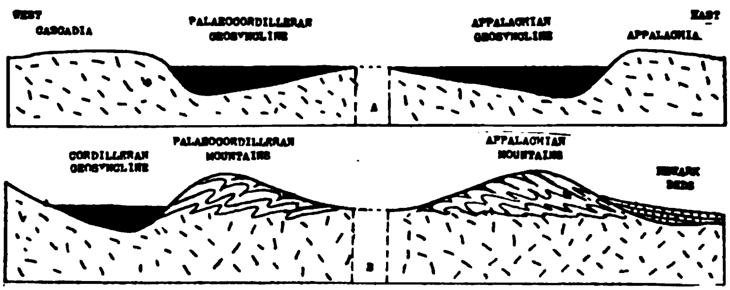


FIG. 1461.—*A*, East-west section through the Palæozoic geosynclines of North America; *B*, Folding of the strata of the geosynclines at the end of the Palæozoic, and migration of the geosyncline toward the oldland. (Original.)

received the Palæozoic sediments. In this new geosyncline and in large part directly upon the old (pre-Cambrian) rocks the Triassic strata of this region were deposited, the clastic sediments being in large measure derived from the newly formed folds on the east of this trough. This will be more fully considered in the description of these strata.

The above diagrams represent east-west sections of the United States: (*A*) during the existence of the older geosynclines (Fig. 1461 *A*), and (*B*) after the folding of their strata and the formation of the early Mesozoic geosynclines (Fig. 1461 *B*).

Europe

The period of intense folding of the Palæozoic rocks of Europe which corresponds to the Appalachian and Palæocordilleran folding, began earlier in Europe than in America, and also terminated earlier. As has already been outlined, the great Palæozoic Alps of Europe arose at this time, consisting of the Armorican chain on the west and the Variscian chain on the east, the two meeting in central France in north-south folds, as the American chains meet in Texas (Fig. 1427, p. 508). In both cases there are secondary east and west folds north of the junction, those in America including the Arbuckle Mountains of Oklahoma, and those of Europe the folded strata of Belgium. The map (Fig. 1427, p. 508) shows the general trend of the folds which had come into existence in Europe by the beginning of Permian time. The Ural Mountains, too, had attained their principal development by this period.

Emergence of the Continents

One of the marked effects of the Appalachian and Palæocordilleran periods of folding in America was the widespread exclusion of the sea from the old troughs and the consequent extinction of the life of these seas. As a result only the more generalized types of the open oceans remained and of these the pelagic forms were probably most favored, while the littoral forms of the continental shelves suffered extinction owing to the narrowing or obliteration of these shelves. Therefore it would appear that the characteristic Mesozoic fauna is in large part a derivation of pelagic survivors of the Palæozoic fauna, with only a small percentage of littoral forms. This probably accounts for the overwhelming abundance of ammonoids in the Triassic and Jurassic faunas, where other animal remains, except vertebrates, are comparatively rare. In the Mediterranean basin of Europe and its continuation in India, etc., the change was less pronounced, and here we find many brachiopods in the Triassic, descended, no doubt, from Palæozoic ancestors.

CHAPTER XL

THE DEVELOPMENT OF LIFE DURING THE PALÆOZOIC

The Palæozoic furnishes us with the first absolutely reliable evidence of the existence of marine life, for although there are remains of organisms in the pre-Palæozoic rocks, these are all forms which may have been, and probably were, characteristic of continental waters, either fresh or of various degrees of salinity. But with the opening of the Cambrian period the record of marine life has become abundant.

Abrupt Appearance of Cambrian Faunas

One of the most marked characteristics of the organic record preserved in the rocks is the abrupt appearance of a diverse and, in many respects, highly organized fauna in which nearly all of the classes except the vertebrates are represented. As we trace the succession of faunas through the Palæozoic, we are impressed with the fact that there is an orderly and progressive development throughout, and it has been possible in many cases to trace this development from period to period and note the steps in the evolution and diversification of Palæozoic life. Stated in another way, a backward tracing of the life of the Palæozoic presents a series of converging evolutional lines, until at the base of the Palæozoic we come to an abrupt stopping point where representatives of all the phyla, except the land plants and the vertebrates, suddenly appear. Only two explanations of this sudden appearance of many and highly organized forms of life seem possible. Either these forms were created as such at the beginning of Cambrian time and thereafter continued to evolve and become differentiated, successively higher types originating, or the base of the Cambrian does not present the earliest record of life but a point far along in the path of organic development. Recognizing the fact that natural forces have governed the development of organic forms throughout not only Palæozoic but all subsequent time, and that nowhere is there any positive evidence of the special creation of organic types, we are forced to accept the latter view as the only tenable scientific explanation of the phenomenon.

Two explanations have been current respecting the absence of the remains of the animals which preceded those preserved as fossils in the earliest Cambrian rocks. It has been thought that the older forms of life did not develop hard structures capable of preservation, partly because the lime of the pre-Cambrian ocean was precipitated chemically; and that this happened because of the presence of a vast amount of decaying organic matter on the sea-bottom, matter which accumulated there because the pre-Palæozoic seas were devoid of scavengers such as in most parts of the modern sea devour all organic matter which reaches the bottom. The chemistry of such precipitation has been outlined in an earlier chapter (p. 247, Pt. I). This view is hardly tenable, for, in the first place, it is not likely that the oceans were ever free from feeders on dead organic matter. Indeed the trilobites from which the Cambrian species were descended were probably voracious bottom-feeders, like their modern relatives the higher crustaceans, while the worms probably were as largely dependent upon such nutriment then as now. In the second place, we cannot conceive that hard structures, such as the exoskeletons of trilobites, came into existence suddenly with the beginning of Cambrian time.

The more rational explanation of the absence of the remains of the ancestors of the Cambrian faunas in the known pre-Cambrian rocks, where they would have been preserved had they been present, is found in the mode of origin of these rocks, which was probably non-marine; that is, that these still little metamorphosed older sediments were deposited in continental waters, and that we do not at present recognize any marine strata among the known pre-Cambrian deposits. That such marine strata were formed cannot be doubted, but they are probably still a part of the material below the younger accumulations on the present sea-bottoms, though some of the highly metamorphosed pre-Cambrian sediments may have had a marine origin. If we recall the vast period of time which is indicated by the erosion surface of the older rocks on which the Cambrian sediments rest, we realize that there is a lost interval of great length during which the organisms in the unknown oceans of that period underwent differentiation. But life did most certainly not commence during this interval, for the vast periods, during which the known older formations accumulated, were undoubtedly characterized by the existence of organisms in the sea. If any of the known older pre-Cambrian strata were of a marine origin, the fossils which they contained were destroyed during the metamorphism which these rocks have undergone.

Development of Palæozoic Organisms

We shall now briefly review the main steps in the development of life during the Palæozoic.

Palæozoic Plants

Algæ. — That algæ existed in the sea throughout Palæozoic time is fully established. Many of them secreted lime, and many of the great limestone formations of this time owe at least a part, and often a very large part, of their origin to these organisms. Such lime-secreting algæ also existed, however, in the continental waters of the time, as shown by Walcott, who considers that the great limestones of the Belt Terrane owe their origin chiefly to

Fig. 1462. — *Marpolia spissa*, a fossil alga from the Middle Cambrian (Burgess) shale of British Columbia, ×2. (After Walcott.)

such lime-secreting algæ, which probably lived in fresh water. The oldest known organism, the *Eozoön* of the Grenville limestone, may also be a calcareous alga rather than a protozoan as was originally held. That forms of this general type, known as *Cryptozoön,* lived in the marine waters of the Cambrian and Ordovician is shown by their abundant development in undoubted marine strata of those periods (see Fig. 1058, p. 261).

FIG. 1463. — *Waputikia ramosa*, a fossil alga from the Middle Cambrian (Burgess) shale of British Columbia, ×2. (After Walcott.)

FIG. 1464. — *Dalyia racemata*, a fossil alga from the Middle Cambrian (Burgess) shale of British Columbia, ×2. (After Walcott.)

Fleshy algæ undoubtedly existed in the Palæozoic seas as they do in modern ones, but with few exceptions they have left no traces. Wonderfully well-preserved examples, however, are known from the Cambrian strata of British Columbia (Figs. 1462–1465). Many impressions in the rocks have been referred to such an origin under the general term of *Fucoids*, but many of these have proved to be mere mechanical markings (Fig. 1273, p. 393).

FIG. 1465. — *Bosworthia simulans*, a fossil alga from the Middle Cambrian (Burgess) shale of British Columbia, ×1½. (After Walcott.)

Land Plants. — When the land plants arose is at present still unknown. The first undoubted remains of such plants are found in strata of Devonian age, but these are already so highly developed that it is clear that they must have been preceded by others during a considerable period of time. We may confidently believe that land plants existed in the Silurian and, if the reported occurrence of insects in the Ordovician may serve as a guide, it would seem that a primitive type of land flora existed in that era as well. It is not impossible that lowly forms, possibly analogous to lichens, covered the rock surfaces at the beginning of Palæozoic time, though no remains have been found to substantiate such a hypothesis. If land plants arose from aquatic ancestors during a period of extensive aridification of the climate on the widespread emergence of the lands, it may well be the case that such an origin falls into the period which preceded the Cambrian transgression.

An important fact to be borne in mind in the study of Palæozoic plants is the high development of the late Palæozoic flora. The lycopods and calamites were on the whole much more specialized than are their modern representatives, which retain many of the characters through which the Palæozoic types passed in their own development (Fig. 1466). They therefore represent a simpler type produced by retardation in development and indicate the declining stages of the race. The same thing is true of the fern-like plants of the later Palæozoic, which had a fructification more nearly akin to that of the cycads than to modern

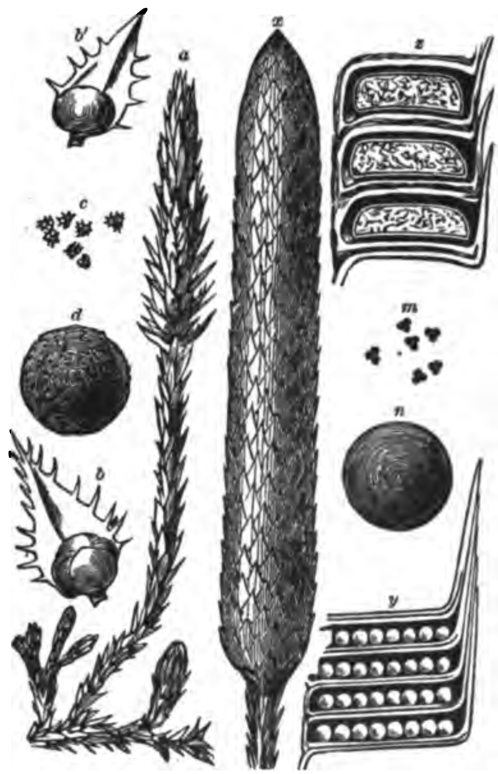


FIG. 1466. — Lepidodendron compared with Club-moss. *a*, Club-moss; *b*, *b'*, scales enlarged; *c*, microspores; *d*, macrospores; *x*, *Lepidostrobus*; *y* and *z*, the scales containing spores; *m*, microspores; *n*, macrospores. (After Balfour.)

forms (Fig. 1467). These cycadofilices, as they are called, likewise represent a lateral branch in development from which may have arisen the cycads and the true flowering plants. The true ferns, on the other hand, which were also represented in the Palæozoic, have continued with but slight modification to the present time (Figs. 810 *a–b*).

The highest type of plants known from the Palæozoic are conifers, among which the cordaites predominate. Trunks of these trees are not uncommon in the late Devonian black shales, having

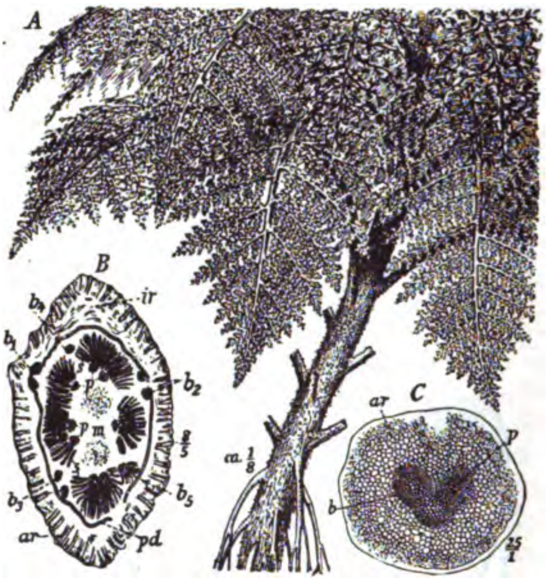


FIG. 1467. — A flowering fern (Cycad fern) of the Upper Carbonic of England. (*Lyginopteris* (*Lyginodendron*) *oldhami*.)

A, Reconstruction of the plant about one-eighth natural size, showing stem, aerial roots, sterile and fertile fronds; *B*, Section of stem: *m*, marrow; *p*, primary wood bundles; *s*, secondary wood; *pd*, periderm, marking outer border of central cylinder; *ir*, inner bark; *ar*, outer bark, with radial bands of sclerenchyma; b_1 -b_5, leaf bundles: b_1, of oldest leaf, $\times\frac{8}{5}$; *C*, Cross-section of stem of frond: *p*, primary wood strands of V-shaped form, surrounded by a ring of bast (*b*); *ar*, outer bark, $\times 25$. (After Steinmann.)

been washed from the lowlands on the south, where they apparently flourished in abundance, into the estuaries in which the black mud accumulated. The leaves of these trees are common in the strata of the coal formations (Figs. 818, p. 86, 1426, p. 505).

Palæozoic Animals

Protozoa. — Foraminifera have been obtained from the Cambrian rocks, and these in all outward appearance resemble modern types of the genera *Globigerina* and *Orbulina* and have been referred to them. It must, however, be noted that the form and larger structure of these shells is relatively simple, and we cannot assume

FIG. 1468. — *Choia carteri*, a Middle Cambrian sponge. Flattened specimen with unusually well preserved spicules, ×1.9. Burgess shale, Middle Cambrian, British Columbia. (After Walcott.)

FIG. 1469. — *Protospongia hicksi*. Portion of spicular mesh of the sponge wall formed of large primary, secondary, and tertiary cruciform spicules, ×2. Burgess shale, Middle Cambrian, British Columbia. (After Walcott.)

FIG. 1470. — *Vauxia hindii*, a Middle Cambrian sponge (Burgess shale) British Columbia. A single branch of a clustered specimen enlarged (3½) showing the ridged surface. (After Walcott.)

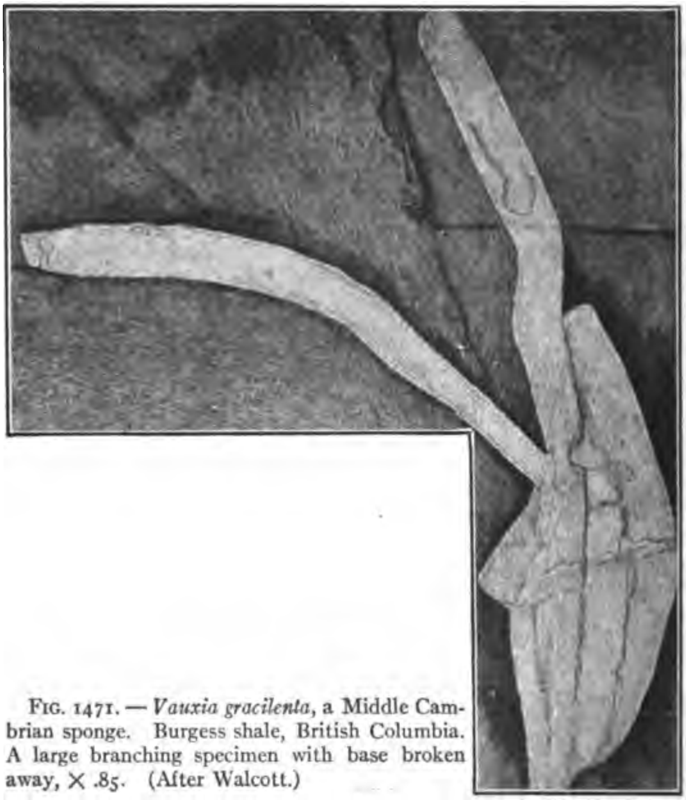


FIG. 1471. — *Vauxia gracilenta*, a Middle Cambrian sponge. Burgess shale, British Columbia. A large branching specimen with base broken away, × .85. (After Walcott.)

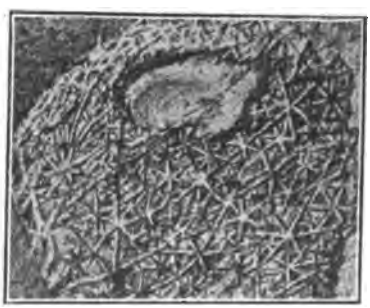


FIG. 1472. —*Eiffelia globosa*, a Middle Cambrian globular sponge, flattened on shale and showing the shallow cup-shaped area (*osculum*) at the summit, and the characteristic spicules (×2). Burgess shale, British Columbia. (After Walcott.)

that because of this similarity of shell-form the Cambrian types were as highly specialized in all respects as are the modern species. The greater specialization of the later forms is primarily in the soft parts, of which no record remains. Foraminifera are found at

FIG. 1473. — *Chancellaria eros*, a slender sponge with spicules showing on the outer surface, slightly reduced. Middle Cambrian Burgess shale, British Columbia. (After Walcott.)

FIG. 1474. — *Chancellaria eros*, part of surface of preceding specimen, enlarged (×3.5). (After Walcott.)

FIG. 1475. — *Takakkawia lineata*, a nearly entire specimen of a small delicate Middle Cambrian sponge (×2) Burgess shale, British Columbia. (After Walcott.)

intervals in the Palæozoic rocks, occasionally becoming so abundant as to be rock-formers. Such is *Endothyra* (Fig. 1371, p. 462) of the Mississippian, and *Fusulina* and *Schwagerina* of the Pennsylvanian and Permian (Figs. 1402, 1403, p. 490). These were all highly specialized and left no descendants in the succeeding periods.

a *b* *c* *d*

FIG. 1476. — Spicules of Cambrian Sponges.

a, b, Chancellaria libo, partially eroded spicules on surface of limestone, Upper Cambrian, Conasauga formation, Murphreys Valley, Alabama, ×3 (after Walcott); *c, C. drusilla*, cast of spicule showing central disk and seven rays, ×3; *d*, sketch of side view of same showing elevated center, ×3. Middle Cambrian, Conasauga shale, Livingston, Coosa Valley, Georgia. (After Walcott.)

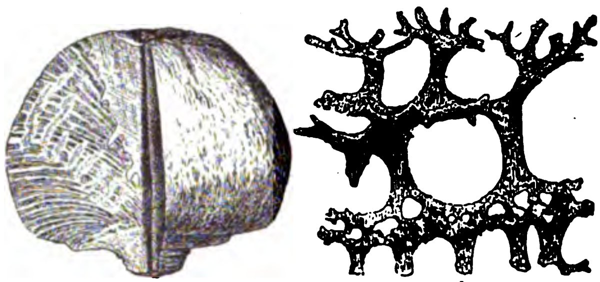


FIG. 1477. — *Aulocopium aurantium*, an Ordovician and Silurian genus of silicious sponge, from Silesia. (After Zittel, *Grundzüge*.)

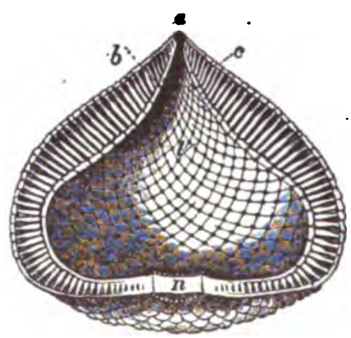


FIG. 1478. — Diagram showing the structure of *Receptaculites*.

a, oral opening or osculum; *b*, internal openings of canals carrying water into the inner cavity *v* of the sponge; *c*, external openings of the canals; *n*, basal portion of sponge. (After Nicholson.)

Radiolaria, too, occurred in the Palæozoic rocks, and the beds of chert in many limestones (Devonian and younger) appear to be largely derived from the solution and redeposition of these silicious organisms. The various types are, however, as yet little known.

FIG. 1479. — Restoration of a portion of the sea-bottom in Neo-Devonian time, illustrating the assemblage of animal life. One of the glass sponges (Dictyospongidæ) is seen attached to the bottom, and a large Devonian *Nautilus* rests upon the sea floor in the foreground. A starfish is also seen clinging to the rock. (From the model in the New York State Museum; after J. M. Clarke, Director.)

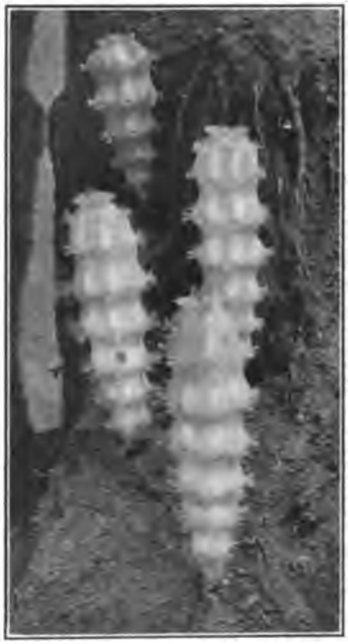


FIG. 1480. — The Glass Sponge (*Hydnoceras tuberosum*) as it appeared in the Devonian sea. From a restoration in the New York State Museum at Albany. (After J. M. Clarke, Director.)

Sponges. — These are not uncommon throughout the Palæozoic, but they are all of types which left no later descendants. Many beautifully preserved examples of ancient sponges are known from the Cambrian strata of British Columbia (Figs. 1468–1475), while sponge spicules have also been recorded from the Cambrian of other localities (Fig. 1476). In the earlier eras the solid, often spherical, forms were common (Lithisdida), some characterized by a shallow or no apical depression (*Astylospongia*, Fig. 1203, p. 358, *Aulocopium*, Fig. 1477, *Hindia*, etc.,), others of doubtful affinities, with a deep inner cavity (*Receptaculites*, Fig. 1478). The body of the sponge is generally a solid mass of rods or spicules which forms a porous structure penetrated by canals which open into the central cavity. One of these (*Brachiospongia*, Fig. 1125, p. 300), probably a hexactinellid, had a ring of marginal

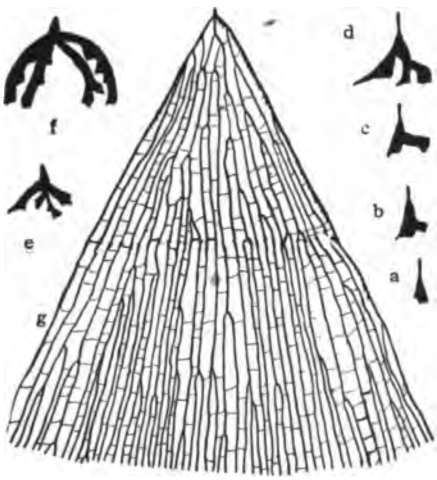


FIG. 1481 *a–g*. — Developmental stages of *Dictyonema flabelliforme*, showing the growth from the embryonic stage (*a*) in which there is only the minute sicula to the adult condition (*g*) in which there are many branching fronds united at short intervals by delicate dissepiments or cross-bars. The sicula, which was the point of attachment and from which the graptolite hung pendent, is still preserved in the adult and some of the tooth-like hydrothecæ are visible.

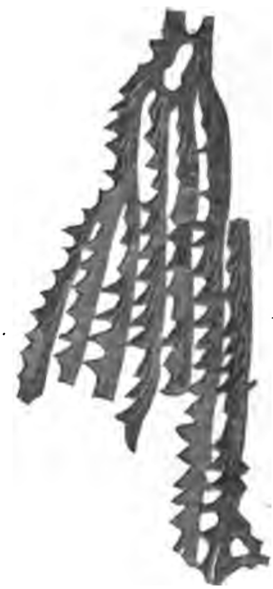


FIG. 1482. — *Dictyonema furciferum*, showing the composite character of the thecæ (×5½) Deepkill beds. (After Ruedemann.)

finger-like prolongations which give the sponge a very striking aspect. In the later Palæozoic the hollow thin-walled group of *Dictyospongias* (Figs. 1479, 1480) (of the order Hexactinellidæ) were very characteristic, these being usually preserved in the rock-filling of the inner cavity, on the surface of which the network of silicious fibers which formed the wall are well marked usually as impressions. In form they range from simple cylindrical to prismatic (Fig. 1303 *b*, p. 418) and transversely wrinkled types, with the intersections of the wrinkles and prism angles in specialized types drawn out into nodes or spines (Fig. 1303 *a*, p. 418).

Graptolites. — These organisms appear suddenly at the beginning of Ordovician or the end of Cambrian time. Two main divisions are recognized, the *Dendroidea*, of which *Dictyonema* (Figs. 1481, 1482) is a typical example, and the *Graptolitoidea*. These consist of a series of tubes or thecæ which bud successively one from the other until a group of more or less irregular branches, each a chain of small conical tubes, is produced (*Bryograptus*,

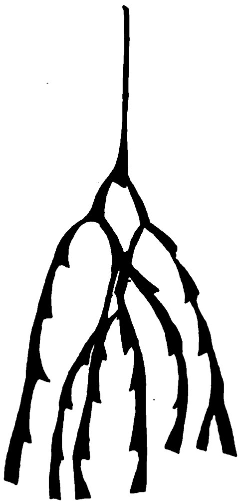


FIG. 1483. — *Bryograptus pusillus* (×7). A primitive graptolite, showing the loose arrangement of the branches and the long, scarcely overlapping thecæ. (After Ruedemann.)

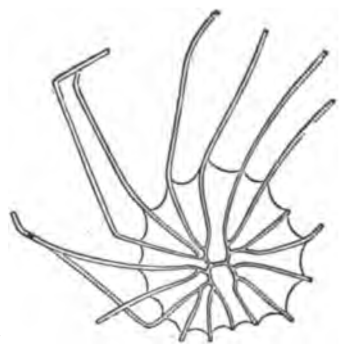


FIG. 1484 *a*. — *Loganograptus* (*L. logani*). Upper end with disk. The number of branches is sixteen or more. Ordovician. (After Nicholson.)

Fig. 1483). From this type on the one hand the dictyonemas developed by continued and rapid budding and the formation of cross-bars, which united the branches into a rigid network of a conical form; and on the other, the simpler graptolites by progressive reduction of the branches from 32 or more to 16, 8, 4, and 2, respectively (Figs. 1484 *a–d*). This progressive reduction suggests that the group as a whole was a declining one, although within each series there was still progressive specialization in the form of the cups, or thecæ, and in their relation to one another in each branch (Fig. 1485). Finally from the four-branched (*Tetragraptus*, Fig.

1486 *a*) and the two-branched types (*Didymograptus*, Fig. 1486 *b*) there developed in each case a series of forms in which the branches

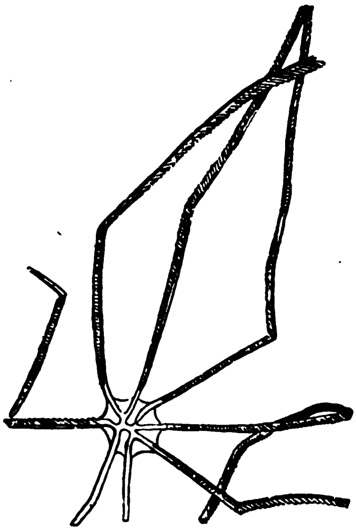


FIG. 1484 *b*. — *Dichograptus* (*D. octobrachiatus*). The number of branches has been reduced to eight. Ordovician. (After Hall.)

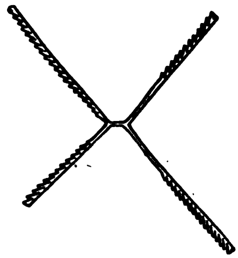


FIG. 1484 *c*. — *Tetragraptus* (*T. quadribrachiatus*). The number of branches has been reduced to four. Ordovician. (After Hall.)

were joined back to back, so as to produce either a cruciform section (*Phyllograptus*, Fig. 1070, p. 266) or a simple, doubly-toothed

FIG. 1484 *d*. — *Didymograptus* (*D. murchisoni*). The number of branches has been reduced to two. Ordovician. (After Hall.)

FIG. 1484 *e*. — *Corynoides* (*C. calicularis*), enlarged. The graptolite has been reduced to a single theca. (Normanskill.) The genus occurs in the Middle and early Upper (Trenton) Ordovician of America and Europe.

branch (*Climacograptus*, Figs. 1487 *a–c*; *Diplograptus*, Figs. 1487 *d–f*), commonly with a rigid supporting rod (virgula) in the

FIG. 1486. — The short and broad-branched graptolites. *a*, *Tetragraptus bryonoides*; *b*, *Didymograptus pennatus*. Lower Ordovician. By the junction of the branches, back to back, the *Phyllograptus* type is produced. (Fig. 1070, p. 266.)

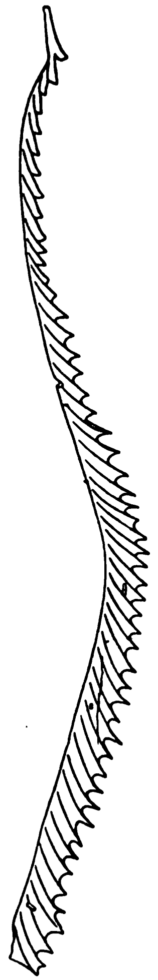


FIG. 1485. — *Tetragraptus*. A single branch, showing the change in form of thecæ from distantly arranged in the young or first formed portion (top) to closely overlapping in the last formed portion of the branch (bottom).

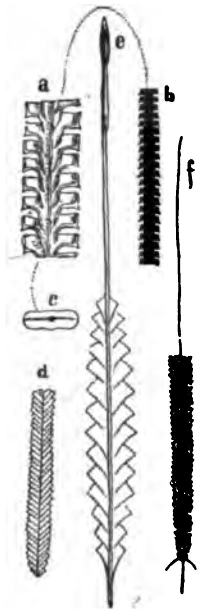


FIG. 1487. — Types of biserial graptolites (Axonophora). *a–c*, *Climacograptus typicalis*, Ordovician (*a*, Enlarged vertical section, showing central rod or virgula; *b*, Individual of natural size; *c*, Cross-section, enlarged); *d–e*, *Diplograptus palmeus*, Silurian (*d*, Individual of natural size, showing closely-crowded thecæ; *e*, Individual enlarged, showing the virgula and sicula); *f*, *Diplograptus foliaceus*, Ordovician, natural size. (After Hall, Barrande, and Lapworth.)

center. Some of the stages in the development of *Diplograptus* are shown in Figs. 1488, 1489. Some of these specialized groups formed colonies by the union of many double branches to a central floating bulb (Fig. 841, p. 100).

Practically all of these types disappeared with the close of the Ordovician, though the Dendroidea continued to the middle or later part of the Palæozoic. One division of the Graptolitoidea, however, arose in the Silurian and continued through the period. This type was characterized by the suppression of one row of thecæ or cups, so that only one side of the supporting rod, or

Fig. 1488. — Sicula of a *Diplograptus*, showing the apical (embryonic) and apertural parts. Note the growth-lines in the latter, and their absence in the early part. (After Ruedemann.)

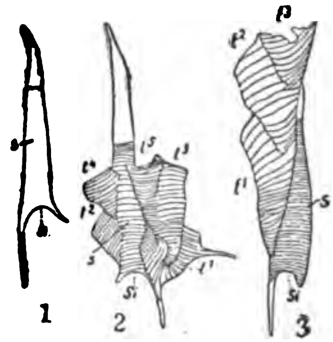


Fig. 1489. — Initial stages of the rhabdosome of graptolites. 1, *Diplograptus gracilis: s*, sicula; 2, sicula of same with first five thecæ ($t_1 - t_5$); 3, *Monograptus dubius:* sicula *s* with the first three thecæ ($t_1 - t_3$); *si*, aperture of sicula.

virgula, was lined by a succession of cups (*Monograptus*, Fig. 1154, p. 318). This form died out at the end of the Silurian.

Stromatoporoids. — These abounded throughout the Palæozoic, but reached their acme of development in the Silurian and Devonian. They consist of large masses or heads of calcareous material built up in successive thin layers of lime, each generally separated from the preceding layer by low rods or spines of lime, with the result that the structure has become more or less cellular (Fig. 847, p. 102). Various surface characters are developed, such as a series of rather regular rounded or nipple-like elevations, each of which may further show a relatively large pore from which branching grooves radiate (astrorhizæ). They probably mark the position of the larger (feeding) polyps of the colonies. In the

Ordovician the principal representatives of this class are *Beatricea* (Fig. 1490), a rod-shaped or columnar mass, fluted externally and with a coarsely cystose structure and *Labechia* (Fig. 1491), a flat expansion of cystose layers traversed by dense vertical rods. The Silurian beds are chiefly characterized by the *Clathrodictyon*

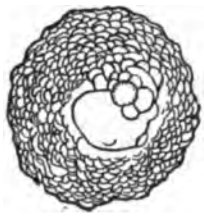


FIG. 1490. — Section of the columnar hydrozoan *Beatricea* (*B. nodulosa*), showing an inner tube around which the calcareous matter is deposited in a series of blisters or cysts. The animal matter covered the outside of the prism. (I. F.)

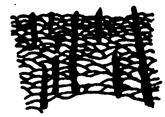


FIG. 1491. — Vertical section of a disk-shaped or expanded Ordovician hydrocoralline (*Labechia ohioensis*) (× 9). The deposit formed by the organism consists of a succession of blister-like or cystose layers, traversed by solid calcareous rods. (I. F.)

type (Figs. 1210 *a–c*, p. 359; 1492) in which the horizontal layers are supported by short vertical rods not continuous through the layers. The Devonian forms, on the other hand, are of the *Actinostroma* type (Figs. 1304, p. 418; 1493) in which the vertical elements are continuous through the layers.

FIG. 1492. — Vertical section of a part of a mass of *Clathrodictyon* (*C. striatellum* ×8) of the Silurian, showing the dominance of horizontal over vertical elements, the latter being spine-like. (I. F.)

FIG. 1493. — Vertical section of a mass of *Actinostroma* (*A. fenestratum*, ×8) of the Devonian, showing the pronounced development of the vertical elements. (I. F.)

Corals. — The most characteristic Palæozoic corals are simple cornucopia-shaped structures, with the radiating plates or septa (visible in the upper depression or calyx) arranged in multiples of four. In the more primitive Ordovician types the septa are arranged in four groups or bundles about the four main septa (Figs. 851, *a*, *b*, p. 104), but in the later types this fourfold arrangement exists only in the young stage, the septa of the adult becoming radially arranged (Figs. 1254, 1306 *f*). A second group had the interior enclosed by the coral wall, filled with cystose or cellular structure which sometimes was arranged in regular layers. Septa in this group were generally much reduced and rested upon the cystose filling (*Cystiphyllum*, Figs. 1306 *a*, *b*). Both these groups also developed compound forms by rapid budding of young from the calyx or side of the parent, which by mutual compression commonly assumed a prismatic form (Figs. 1307 *a*, *b*). Slender, tubular corals with the septa largely or wholly suppressed, but with conical or flat transverse divisions, also abound. These are either loosely aggregated, their tubes held together by short branches (*Syringopora*, Figs. 1206, p. 358, 1255, p. 383) or crowded and prismatic with the walls pierced by numerous pores (*Favosites*, Fig. 853, p. 104). Intermediate between the two groups is the Silurian chain coral (*Halysites*, Fig. 1161, p. 320), in which the tubes are closely adjoined only on one side.

All of these types practically disappeared at the end of the Palæozoic, especially in America where no relation exists between the Palæozoic and the Mesozoic types.

The ancestral corals, probably simple tubes without septa, appear to have lived in Cambrian time; their differentiation into septa-bearing and septa-less groups took place in the Ordovician, and both groups reached their acme of development in the Devonian when they migrated far and wide over the world. Then a decline set in and by the end of Palæozoic time the older types had disappeared. With the reëstablishment of the interior seas in Mesozoic time appeared a new race of corals in which the septa rather than the wall constituted the primary structure, and in which the parts were developed in multiples of six instead of four.

Bryozoa. — These organisms appear abruptly in Ordovician time, where almost at the outset forms of considerable complexity occur. Hence we conclude that though they are not known from Cambrian strata, they nevertheless existed at that time in some of the oceans, and that their apparently sudden appearance is due to invasion of new territory from the unknown centers of origin. There are, of course, many primitive forms, but they are at present known only from the Upper Ordovician and younger rocks.

The bryozoans began as a series of calcareous cells with more or less contracted apertures which at first grew in simple chains, one budding from the other (Figs. 1494 *a*, *b*). By branching and by the lateral confluence and union of the branches flat expansions were produced (Figs. 1494 *c*, *f*, *g*), while by further rapid budding on all sides, rod-like, finger-like, disk-like or other masses composed

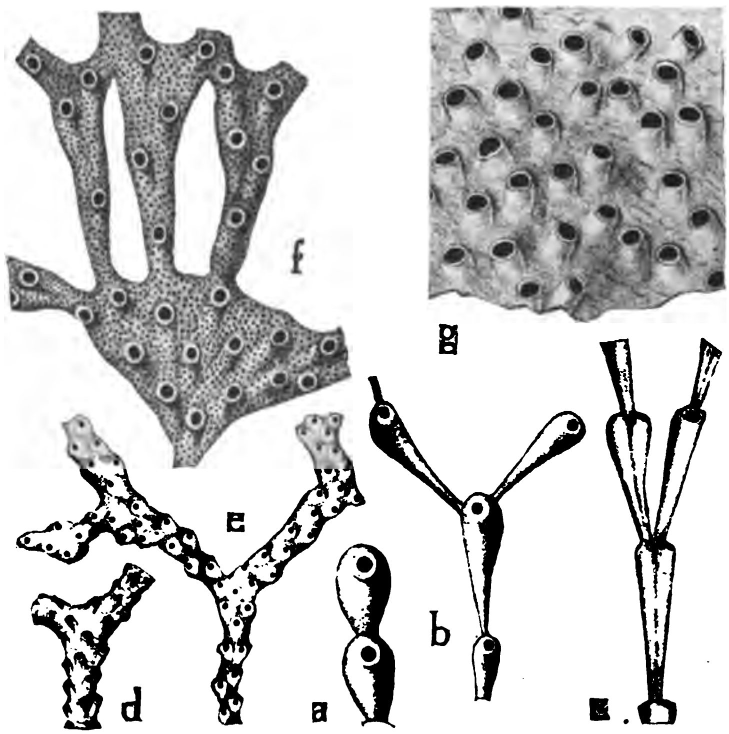


FIG. 1494. — Palæozoic Bryozoa ranging from simple to complex types.

a, *Stomatopora inflata*, consisting of simple, pear-shaped cells (× 13); *b*, *Stomatopora delicatula*, with longer, more slender cells and single branches (× 19); *c*, *Phacelopora pertenuis*, with the segments arranged in linear series, doubly branched, each segment consisting of two zoœcia (× 19); *d*, *Mitoclema mundulum*, with zoœcia crowded and arranged in a spiral series which form branches (× 7); *e*, *Proboscina tumulosa*, with crowded zoœcia arranged in double or triple rows forming branches (× 7); *f*, *Proboscina frondosa*, with branches reuniting at intervals, each branch containing many zoœcia (× 19); *g*, *Berenicea minnesotensis*, a form with zoœcia growing in irregular rows on a flat surface (× 19). (I. F.)

of numerous minute prismatic tubes resulted (Figs. 1494 *d*, *e*). Such prisms characterized the so-called *Monticuliporoids*, which were typical of the earlier Palæozoic. In the later Palæozoic the development of branches became more regular, forming fan-like expansions with transverse connecting bars, producing a latticelike structure (*Fenestella*, etc., Fig. 1313, p. 423). When these fan-shaped expansions developed upon a spiral axis, the characteristic Mississippian genus *Archimedes* resulted (Fig. 1375, p. 464). Most of the Palæozoic forms disappeared at the end of that time, the Mesozoic and later types being derived from a few members of the older bryozoan fauna. Two orders, *Trepostomata* and *Cryptostomata*, the former including most of the coral-like monticuliporoids and the latter the fenestelloid types, are practically confined to the Palæozoic. The remaining Palæozoic Bryozoa belong to the order of *Cyclostomata* or forms with round pores, but this order is chiefly represented in Mesozoic and younger formations. In the Palæozoic they are largely confined to the Ordovician (Fig. 1494).

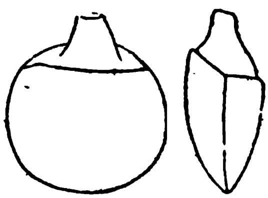


FIG. 1495. — Early stage of *Cystella*, a modern form, representing essentially the characteristics of the adult *Paterina*, one of the earliest and most primitive Cambrian brachiopods. Much enlarged. *a*, front; *b*, side views. (After Hall & Clarke.)

Brachiopoda. — The oldest brachiopods from the Cambrian deposits are mostly horny-shelled types, though forms with calcareo-phosphatic shells also occur. The oldest and most primitive form from the Lower Cambrian of Vermont has nearly equal valves with an opening for the pedicle shared equally by both, a character repeated in the earliest shell stages of later brachiopods (Fig. 1495). From this type other characteristic early Palæozoic forms are derived by the greater development of one or the other valve, the formation of hinge areas, etc. Among the most generally distributed Cambrian genera are those of the *Obolus* group and the *Lingulas* (Fig. 1496). The latter continue to the present day, but it must not be supposed that the Palæozoic *Lingulas* were as highly organized as are the modern ones, though the general form and character of the shell remained much the same throughout (Fig. 872, p. 115). These brachiopods belong to the order *Atremata*, in which the pedicle emerged between the two valves. Other characteristic Cambrian types include *Obolella*, *Acrotreta*, and *Acrothele* (Fig. 1013, p. 228), more or less corneous or calcareo-corneous shells of circular outline, often of conical form, and with the apex of one valve pierced for the emission of the pedicle. These belong to the order *Neotremata* and here also are placed many Palæozoic types in which the pedicle opening forms a notch in the margin of one valve (*Trematis*, etc., Figs. 1133 *v, w*), which may later be partly filled in by the growth of a new calcareo-corneous plate, so that secondarily the pedicle passes through a slit-like opening (*Orbiculoidea*, Fig. 1497). Finally there are a number of Palæozoic forms which become attached to other objects more or less completely by one valve (*Crania*, Figs. 1498 *a, b*) some species of *Strophalosia* (Fig. 1498 *f*) and others, while one form, at least,

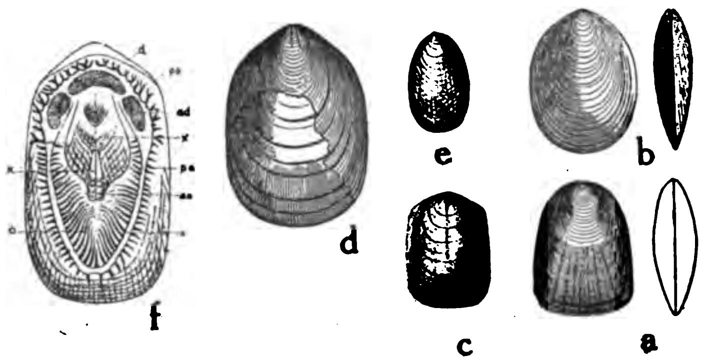


FIG. 1496. — A group of Palæozoic Lingulas. *a*, *Lingula eva* (Black River); *b*, *L. rectilateralis* (Trenton–Lorraine); *c*, *L. modesta* (Trenton–Lorraine); *d*, *L. coburgensis* (Trenton); *e*, *L. ligea* (Hamilton–Portage); *f*, *L. elderi*, interior of dorsal valve, showing muscular and vascular markings. (After Whitfield.)

d, Divaricator muscular scars; *ad*, adjustor muscular scars; *pa*, posterior adductor scar; *a, a*, anterior adductor scars; *xx*, track of advance of the muscular scars; *s*, great pallial sinuses; *ps*, posterior course of the latter; *o*, inner ramifications of the sinuses. (After Whitfield.)

appears to have led a free-swimming existence (*Pholidops*, Figs. 1498 *c–e*).

In the Cambrian, too, arise the first members of the *Orthis* group in which the valves are held together or articulated by the development of tooth-like projections in the pedicle valve, which fit into sockets in the opposite valve. A straight hinge-line and a flattened cardinal area also characterize these shells, which are commonly plicated. At first (Cambrian and early Ordovician) the pedicle valve is convex and the brachial valve nearly flat. Then the valves become more equal in convexity, and finally the brachial valve becomes the more convex while the pedicle valve tends to become flatter or even concave. Two groups are recognized, one with the hinge-line forming the greatest width of the shell, and these are largely confined to the older Palæozoic. In the younger divisions, however, the short-hinged, more or less circular forms become very characteristic, and undergo the same change from bi-convex forms to those with flat or concave pedicle valve (Figs. 1499 *a–g*).

Another characteristic group of brachiopods is that of the strophomenoids. Beginning in the Ordovician, these shells are

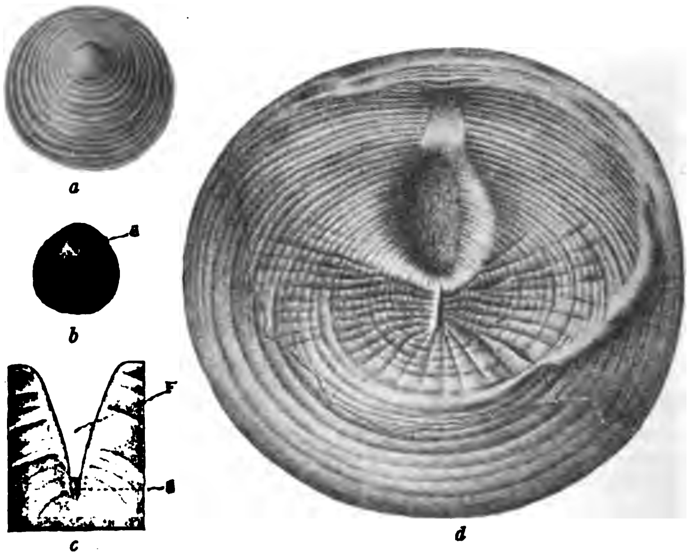


FIG. 1497. — Discinoid brachiopods of the Palæozoic.

a, *Orbiculoidea pulchra*, the exterior of the brachial valve × 1.5 (Lower Mississippian); *b*, *O. media*, exterior of a pedicle valve (Upper Devonian); g, *listrium* or plate covering the opening, foramen, through which the pedicle projects; *c*, *O. nitida*, the pedicle-area of an extremely young shell (diameter 1 mm.) showing the open slit-like foramen (*F*) which later becomes closed (as in *d*) × 50; g, beginnings of the *listrium* (Lower Coal-measures); *d*, *Orbiculoidea randalli*, exterior of a pedicle valve (Middle Devonian), natural size. The shell is compressed, showing the apical muscular ridges, the radiating mantle grooves (pallial sinuses) and the internal track of the pedicle furrow. These do not ordinarily show on the exterior. (After Hall and Clarke.)

characterized by their long hinge-line with narrow areas and the gently convex character of one and corresponding concave character of the other valve. These types are mainly represented by *Rafinesquina* and the reversed *Strophomenas* in the Ordovician (Fig. 1133 ll′), and by the similar forms with notched hinge-line — the genera *Stropheodonta* and the reversed *Strophonella* in the Silurian and Devonian (Figs. 1500 *a–d*). In still higher horizons similar forms, mostly reversed, continue (*Orthothetes, Schuchertella*); while the series is terminated in the Mississippian and Pennsylvanian by the degenerate *Productus* with extremely convex pedicle and concave brachial valve and obsolete hinge-area, but generally with a pronounced development of spines all over the surface (Fig. 1407). Lateral evolutional branches are represented in the very transverse *Plectambonites* (Fig. 1066 *f–h*, Ordovician and Silurian) and the similar form with spines on the hinge-line

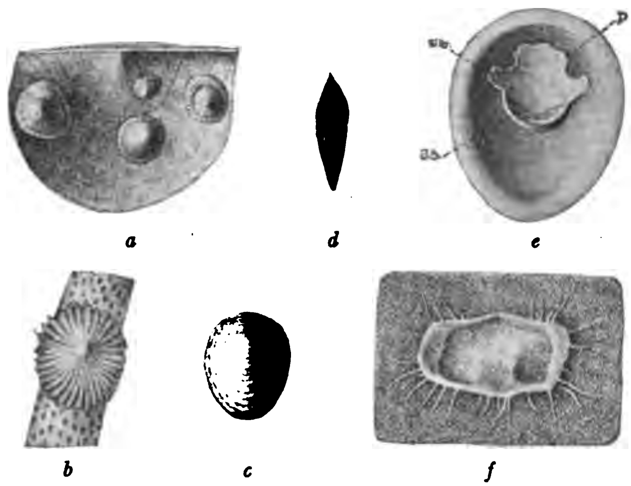


FIG. 1498. — *a–f*, Types of attached (*a, b, f*) and free (*c–e*) brachiopods.

a, b, Crania (*a, C. lælia* attached to *Strophomena*, Upper Ordovician; *b, C. pulchella*, attached to a bryozoan, × 2, Helderbergian). *c–e, Pholidops* (*P. hamiltoniæ; c*, view of valve × 2; *d*, profile of conjoined valves × 2; *e*, interior showing muscular area × 4; *pa*, posterior, *aa*, anterior adductors, *p*, parietal impression, Middle Devonian); *f, Strophalosia radicans*, a pedicle valve attached by spines to a bryozoan, × 2, Middle Devonian. (All after Hall and Clarke.)

(*Chonetes*, Fig. 1501, Silurian to Pennsylvanian). Another peculiar modification of the strophomenoid type is *Leptæna* (Fig. 1502), which is characterized by concentric undulations and an abruptly bent-down outer portion. This was especially abundant in the middle Palæozoic.

Very characteristic of the Palæozoic are the pentameroid shells, usually smooth but often plicated, in which the interior is divided by vertical partitions, two in the brachial and one in the pedicle valve which divides beneath the beak to form a spoon-shaped structure (spondylium). They range throughout the Palæozoic but are most characteristic of the Silurian and Devonian (Figs. 1153, 1213 *c*, 1247). The Palæozoic rhynchonelloid shells are usually strongly plicated and without hinge area. Many genera

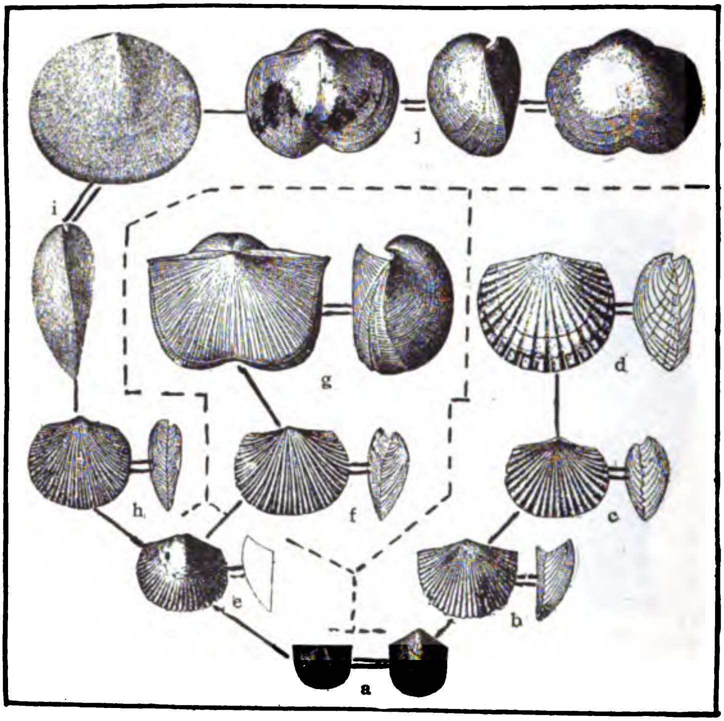


FIG. 1499. — American species of *Orthis* arranged to illustrate the several lines of development.

I. *a*, **Billingsella** (*B. coloradoensis*), Cambrian; strongly convex pedicle, nearly flat brachial, valve, long hinge; *b*, **Orthis** (*O. tricenaria*), long hinge, deep pedicle, shallow brachial, valve, coarse plications, Middle Ordovician (Stone's River); *c*, **Plectorthis** (*P. plicatella*), long hinge, valves nearly equally convex, coarse plications, early Upper Ordovician (Trenton–Lorraine); *d*, **Dinorthis** (*D. pectinella*), early Upper Ordovician (Trenton), long hinge, coarse plications, pedicle valve the shallower. II, *e*, **Orthis** (*O. costalis*) Middle Ordovician (Chazy), long hinge, fine plications (due to repeated intercalation), pedicle valve strongly convex, brachial valve flat; *f*, **Plectorthis** (*P. fissicosta*), Upper Ordovician (Lorraine), long hinge, fine plications, valves nearly equally convex; *g*, **Hebertella** (*H. alveata*), Upper Ordovician (Lorraine), long hinge, fine plications, pedicle valve shallow, brachial valve strongly convex. III, *h*, **Dalmanella** (*D. testudinaria*), early Upper Ordovician (Trenton), short hinge, fine plications, valves nearly equally convex; *i*, **Rhipidomella** (*R. vanuxemi*), Middle Devonian (Hamilton) (the genus ranges from the Silurian on), short hinged (round form), fine plications (striations), pedicle valve less convex than brachial; *j*, **Schizophoria** (*S. striatula*), Upper Devonian, short hinged, fine plications, pedicle valve shallow, brachial valve strongly convex. (I. F.)

Almost restricted to the Palæozoic and exceedingly characteristic of it are the spire-bearing brachiopods in which the support of the fleshy arms is twisted into a pair of spiral cones. The earliest of these occur in the Ordovician *Protozyga*, *Cyclospira*,

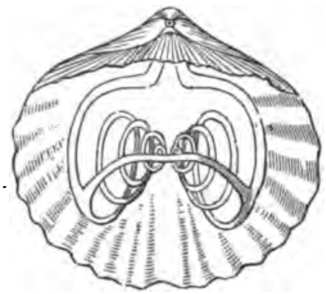


FIG. 1504 *c*. — The more complex spiral arm supports of *Zygospira modesta*, late Upper Ordovician. (Eden-Richmond.)

FIG. 1504 *d*. — A Silurian form with simple outward-coiling spirals. (*Dayia navicula*, Niagaran of Europe.)

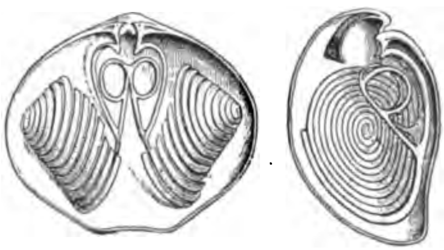


FIG. 1504 *e*. — *Merista herculea*. Lower Devonian, Bohemia, showing the highly complex characters of the spiral arm supports. (Davidson.)

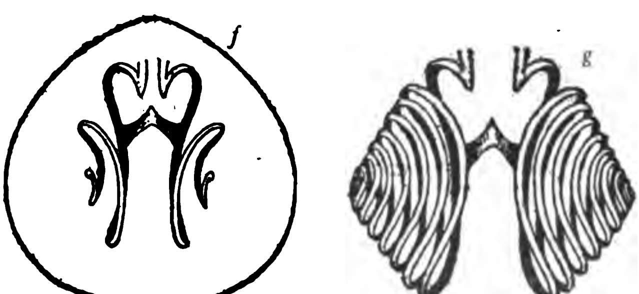


FIG. 1504 *f*. — The brachidium of *Rhynchospira* (*Homæospira*) *evax*. *f*, A very early stage of growth; *g*, the mature condition. (This is a plicated shell.) (After Beecher and Clarke.)

Zygospira, Figs. 1504 *a*–1504 *c*), but there are few species. In the Silurian and Devonian they are exceedingly abundant. The principal forms are *Atrypa*, a finely plicated shell with extremely convex brachial valve into which the spires project and without hinge-area

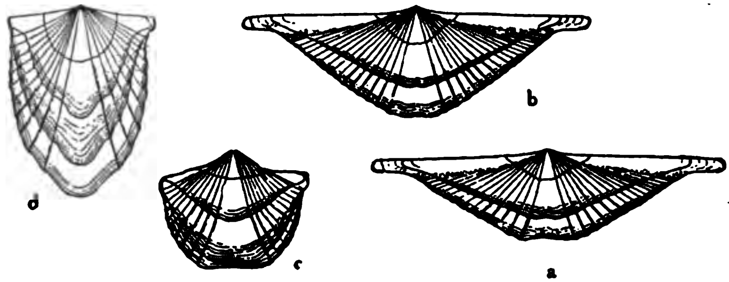


FIG. 1505. — A series of specimens of *Spirifer mucronatus* (Middle Devonian, Hamilton group), showing the variation in form, and the change with increase in size.

a, shows the laterally extended or "mucronate" mutation, characteristic of the lower beds; *b*, is relatively higher, but the prominent growth-line of the immature shell shows that before it had reached its full growth it had the proportions of the adult shell (*a*) in the lower beds; *c*, shows extreme shortening, characteristic of the species in the highest beds. Because of the curvature of the shell the relative dimensions are not appreciated. These are shown in *d*, which is the shell *c* flattened out, giving true proportion of length and width. The half-grown shell in this variety is much shorter proportionally, approaching more nearly the adult of mutations in lower horizons. (From *Principles of Stratigraphy*.)

in the adult (Fig. 873, p. 115), *Dayia*, *Whitfieldella*, *Merista*, etc., bi-convex smooth shells without hinge-area and with laterally projecting spirals (Figs. 1504 *d*–*g*); and *Spirifer* (Figs. 1505, 1506), transversely elongate, plicated or non-plicated shells, with well-developed hinge-area and laterally extending, strong, internal spirals.

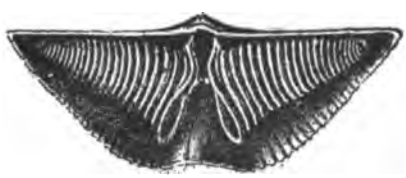


FIG. 1506. — *Spirifer mucronatus*. Interior of brachial valve, showing spirals, Middle Devonian. (After Hall and Clarke.)

Upwards of 3000 species of brachiopods are known from the Ordovician and the Silurian and perhaps half as many from the Devonian, these being the three eras of brachiopod supremacy. In the later Palæozoic they decline rapidly and most of the genera disappear towards its close. The Mesozoic and younger types are mostly descendants of Palæozoic rhynchonelloids, terebratuloids, and a few others. The Palæozoic was preëminently the age of brachiopods.

Pelecypoda. — These bi-valved Mollusca appear rather suddenly in the Middle Ordovician, though there are two small forms of doubtful affinity found in the Cambrian. The early Palæozoic pelecypods are in the main characterized by having a large

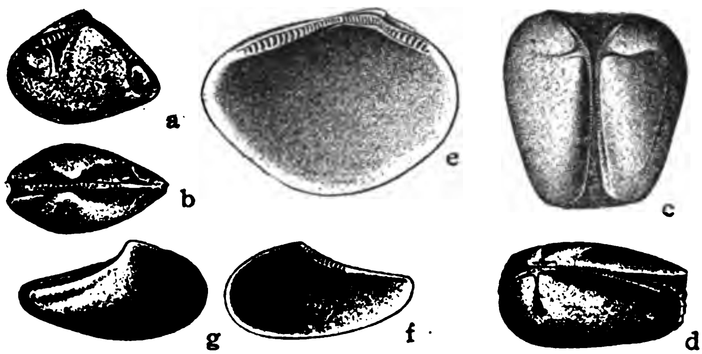


FIG. 1507. — A group of Palæozoic pelecypods with primitively notched (taxodont) hinge-line. This is the type of hinge characteristic of the earliest shell-stage (prodissoconch) of later pelecypods.

a, *Ctenodonta gibberula*, Ordovician (Stones River); *b*, *C. obliqua*, internal mold, Ordovician (Cincinnatian); *c*, *d*, *Nuculites oblongatus*, internal molds, Middle Devonian (Hamilton); *e*, *Paleoneilo constricta*, enlarged, Devonian (Hamilton); *f*, *g*, *Leda pandoriformis*, interior of shell, and internal mold; Mississippian (Waverlyan).

number of simple and similar teeth on the hinge-line (taxodont types, Fig. 1507) which recall the hinge-characteristics of the early or prodissoconch stage of modern pelecypods (Figs. 1508 *a–c*). Mussel-like shells (*Modiomorpha*, etc., Fig. 1509) are very characteristic of the Devonian. On the whole, plicated shells, so common to-day, are not very frequent in the Palæozoic, where shell ornamentation is seldom carried very far. Hence the form and hinge-structure have largely to be relied upon for the differentiation of genera and species, and little can be said in the way of general characters of the group in Palæozoic time. The acme of development of this group falls in Tertiary and recent times. The majority of Palæozoic forms belong to the order *Prionodesmacea*, the other two orders being represented by only four families, three of which are restricted to the Palæozoic.

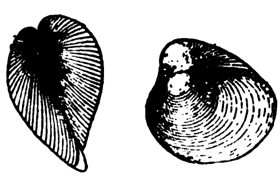
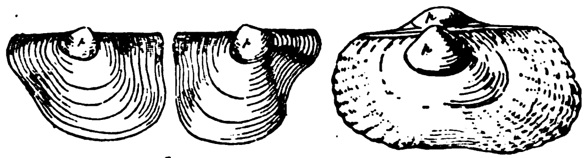


FIG. 1508 *a*. — The early embryonic shell or *prodissoconch* of the oyster (*Ostrea virginiana*). Much enlarged. (After Jackson.)

Gastropoda. — These are also represented by primitive forms, this class, like the preceding, having reached its highest development at the present time. The chief Palæozoic types are the Bellerophons, coiled in a single plane and with a notch or slit in the



b *c*

FIG. 1508 *b, c*. — **Embryonic shell stages (prodissoconchs, *p*) in their normal relationship to the later shell-stages, enlarged; *b, Avicula;* right and left valves;** *c, **Arca pexata***. (After Jackson.)

outer margin (Figs. 1135 *j–p*); the Pleurotomarias, coiled in snail-like manner but varying greatly in height and form of spire, also with a slit or notch in the outer or upper margin

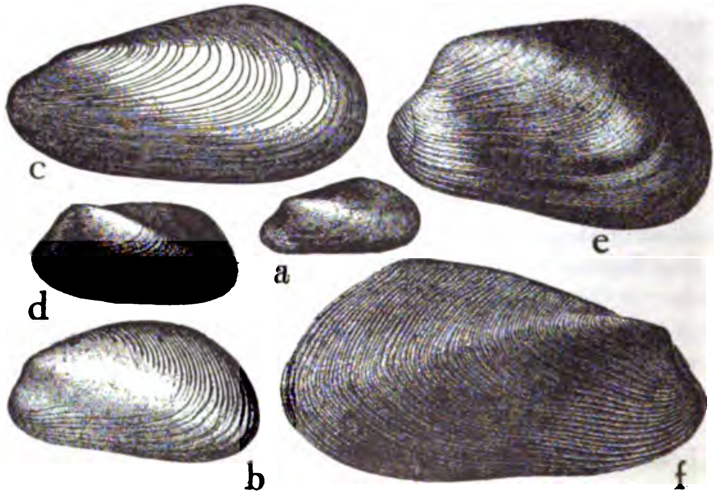


FIG. 1509. — A series of Palæozoic mussel shells or Modiomorphas. These have, in their adult stages, the form and characters found in the young of Mesozoic and modern mussels to which they hold ancestral relationships.

*a, **Modiolopsis mytiloides***, Upper Ordovician (Trenton); *b, **M. concentrica***, Upper Ordovician (Cincinnati); *c, **M. modiolaris***, Upper Ordovician (Lorraine); *d, **Modiomorpha subalata**; e, M. alta; f, M. concentrica; (d–f,* Middle Devonian, Hamilton). (I. F.)

(Figs. 1135 *a–i*; 1318 *a, b*; 1411 *g–j*); and various simple coiled shells with entire margins (Figs. 1380 *a, b*). Types are frequently found which have lost the power of coiling (*Platyceras*, etc., Figs. 1318 *g–o*). In the Cambrian the gastropods are chiefly represented by cap-shaped types (Figs. 1016 *a*, 1017 *a–d*) in which the coiling has not yet been developed. They are similar in form to modern limpet shells (*Patella*, *Acmæa*, Figs. 883, 888 *y*, *z*) but these modern forms have usually a more or less well-coiled young stage, showing that their form is not primitive. The Palæozoic patelloids, on the other hand, represent the earliest form of gastropod shells and the entire evolutionary history of these organisms appears to date from the Cambrian. Very many of the Palæozoic types represent side lines in development and died out completely; others have post-Palæozoic descendants.

Air-breathing gastropods (Pulmonata), represented to-day by land snails, appear to have arisen in Silurian time (*Hercynella*, Fig. 1220), if not earlier. They and the fresh-water forms were, however, not common until Mesozoic and Tertiary time. To-day of the twenty thousand or more species of gastropods known, perhaps two fifths are air-breathers.

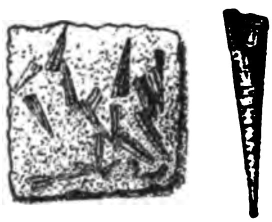


FIG. 1510. — *Styliolina fissurella*, a minute pteropod shell of the Middle and Upper Devonian. Fragment with numerous individuals enlarged three times; and a specimen much enlarged. (After Hall.)

Pteropoda and Conularida. — True pteropods seem to be represented in the Palæozoic by the genus *Styliolina* (Fig. 1510), a small slender tube, showing only lines of growth, and occurring in vast numbers in the Devonian rocks of America and Europe and closely resembling some modern forms (*Styliola*, Fig. 890). In the Cambrian the group is represented by the *Hyolithidæ* (Figs. 1017 *e–i*, p. 230), slender tubes of varying cross-section, and in the typical form with one side produced lip-like anteriorly. Other more flaring and shorter tubes, *Salterella* (Fig. 1017 *j–k*), referred to the Conularida, are also very abundant in certain Cambrian strata. But the *Tentaculites* (Fig. 1175), slender thick-walled tubes marked by a more or less regular series of annulations or rings, are most characteristic of the Silurian and Devonian, while the larger angular tubes with cross-striated, flat or medially depressed sides, known as *Conularia* (Fig. 1511), range from the Ordovician to the Jurassic but are most characteristic of the Palæozoic (Ordovician to Devonian).

Cephalopoda. — The earliest known cephalopod shell is found in the Lower and Middle Cambrian of Europe and America (*Vol-*

borthella, Fig. 1512). It is a minute straight cone with conical septa and, apparently, a simple, small, central siphuncle. From this form on the one hand was derived the orthoceran shell, the most persistent of the Palæozoic cephalopods, and on the other the endoceran and related types (*Holochoanites*, Fig. 1136 *f*, p. 305) which had an enormous development in the Ordovician but practically died out at the end of that era, there being few survivors in the Silurian. This group has an inner tube, filled with conical septa, which are closely crowded so as to produce a solid filling, but which still retain the central siphuncle (endosiphuncle) (Figs. 1513 *a*, *b*). Such a structure would be produced by the close crowding of the

FIG. 1511. — *Conularia micronema*, Mississippian (Waverly group).

FIG. 1512. — The oldest known cephalopod shell, *Volborthella tenuis*, from the Middle Cambrian of the Atlantic province (Eastern Canada, Sweden, etc.). Natural size. This is an orthoceran shell with simple funnel-form septa, and is ancestral to both the Endoceran and the Orthoceran lines of development. (I. F.)

septa of *Volborthella*. This central tube, the wall of which is wanting in the later stages of specialized types, is inclosed in a larger shell in which distinct chambers are developed, nearly but not quite surrounding the inner tube which generally lies on one side of the outer shell. Many modifications were developed during the Ordovician and even some curved forms arose. Some of these shells reached a very large size and were of an exceedingly massive character.

The orthoceran shell was apparently formed by the flattening of the conical septa of the ancestral type until they were saucer-shaped, and by modifications of the siphuncle. It was a much lighter shell with many air chambers (Fig. 898, p. 130) and probably on this account was the successful type which dominated the waters of the oceans throughout most of Palæozoic time (Fig. 1514). Beginning with the Ordovician period, these orthoceran types successively invaded the epeiric seas wherever the conditions of existence were favorable. Once within those shallow provincial water bodies, they quickly developed a great series of modifications, the most pronounced of which was in the manner of growth. By more rapid growth on one side, curved forms resulted (cyrtoceran, Fig. 899). This curved form of growth was inherited early by

FIG. 1513 *a*. — Longitudinal section of the shell of *Endoceras*, showing the solid inner core formed of successive funnel-like layers, pierced by a fine central tube (not revealed in this section) and surrounded by the air chambers. (See Fig. 1136 *f*, p. 305.) (From Zittel, *Grundzüge*.)

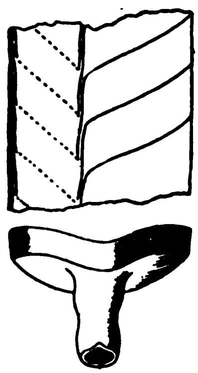


FIG. 1513 *b*. — Diagrammatic longitudinal section of a primitive orthoceran cone (*Vaginoceras commune*) from the Ordovician of Russia, and detached chamber or camera of *Vaginoceras* with its funnel-form prolongation. (After Dewitz.) Note the overlapping character of the septal prolongations or "funnels." (From Zittel, *Grundzüge*.)

the succeeding generations, which assumed this method of growth to a more pronounced degree. As a result spirally coiled shells (gyroceran, Fig. 900) were produced, and as the inequality of growth increased, the outer or ventral portion gaining constantly on the inner or dorsal portion, this latter side came in close contact with the preceding whorl and finally became indented by it before that part of the shell was hardened by the deposition of lime. This indented portion, the so-called impressed zone, became more and more pronounced, so that the later whorls covered the older to an increasing degree and developed the Nautilus type (Fig. 902). Many such with moderately impressed zone were developed in the Ordovician (Figs. 1136 *d*, *e*); some of these in their later stages, however, again lost this power of unequal growth, so that the final portion of the shell was again built straight. This is taken to indicate that the vigor of that particular group is on the decline, so that characters developed early in life are lost again in old age or even in adulthood. These forms died out at the end of the Ordovician, and the Silurian epeiric seas were invaded by a new series of

FIG. 1514. — Restoration of an Upper Devonian sea-bottom, showing an *Orthoceras* with the head and tentacles projecting from the end of the shell which lies upon the sandy bottom amidst the seaweeds. Two of the small primitive fish of the period are shown, as well as an expanded starfish. From the model in the New York State Museum at Albany. (After John M. Clarke.)

orthoceran types which again gave rise to curved and coiled forms, forming parallel series to those of the Ordovician. The same thing happened in Devonian time and again in the Mississippian. In each successive period, however, the power of curved and coiled growth was acquired more quickly than in the preceding, so that the dominant forms of each period showed an advance over those of the preceding one. Thus in the Silurian the curved or cyrtoceran types predominated, in the Devonian the loose-coiled or gyroceran, and in the Mississippian and Pennsylvanian the close-coiled nautilian type. Thus the race made progress on the whole, though in each case certain families progressed more rapidly than the majority and reached a condition of close coiling, or a nautiloid character. In the later Palæozoic the nautiloids underwent many modifications of form (Figs. 1515, 1516).

In the Devonian certain Nautilus types underwent a new modification by the excessive enlargement of a part of the shell-building layer or mantle, which in consequence became too large to fill the cavity of the shell (living chamber) and so was crowded into a series of marginal flutings or folds. We may illustrate this by comparing the animal's body with a rubber pouch, cylindrical at the top but flaring at the bottom. If such a pouch were crowded into a cylindrical tube of rigid material the inner

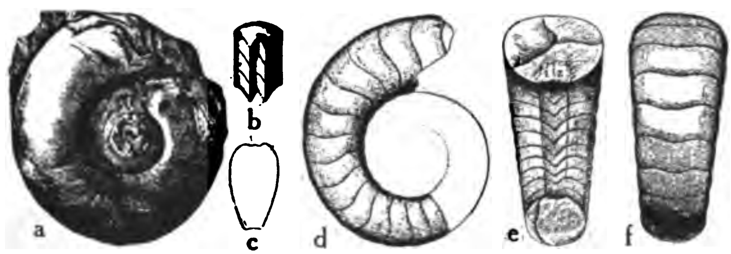


FIG. 1515 *a–f*. — Mississippian nautiloids: *a–c*, *Apheleceras disciforme*, $\times \frac{1}{2}$; *b*, inner side of whorl showing septa, $\times \frac{1}{3}$; *c*, transverse section, $\times \frac{1}{3}$; Keokuk of Illinois. *d–f*, *Remeleoceras clarkense*, $\times \frac{3}{4}$; *e*, inner side of whorls, showing impressed zone (*iz*); *f*, outer or ventral side of whorl; Knobstone of Indiana. Note that these nautiloids are but slightly involute.

diameter of which is just equal to the upper cylindrical part of the pouch, it is evident that the lower, flaring part of the pouch would have to be crowded into a series of folds or flutings in order to fit into the cylindrical tube which represents the shell of the animal. If a partition were built across the tube at the bottom of the pouch, so that the form of the partition corresponded exactly to its bottom, it is evident that this partition or septum would be smooth in the center but fluted at the margins where it joins the outer tube. In other words, the septum by itself will have the appearance of a saucer with a fluted margin. It is also evident that the more flaring the bottom of the pouch the more intricate will be the folding as it is crowded into the cylinder and the more complex will be the fluting of the margin of the septum built to conform to its bottom surface.

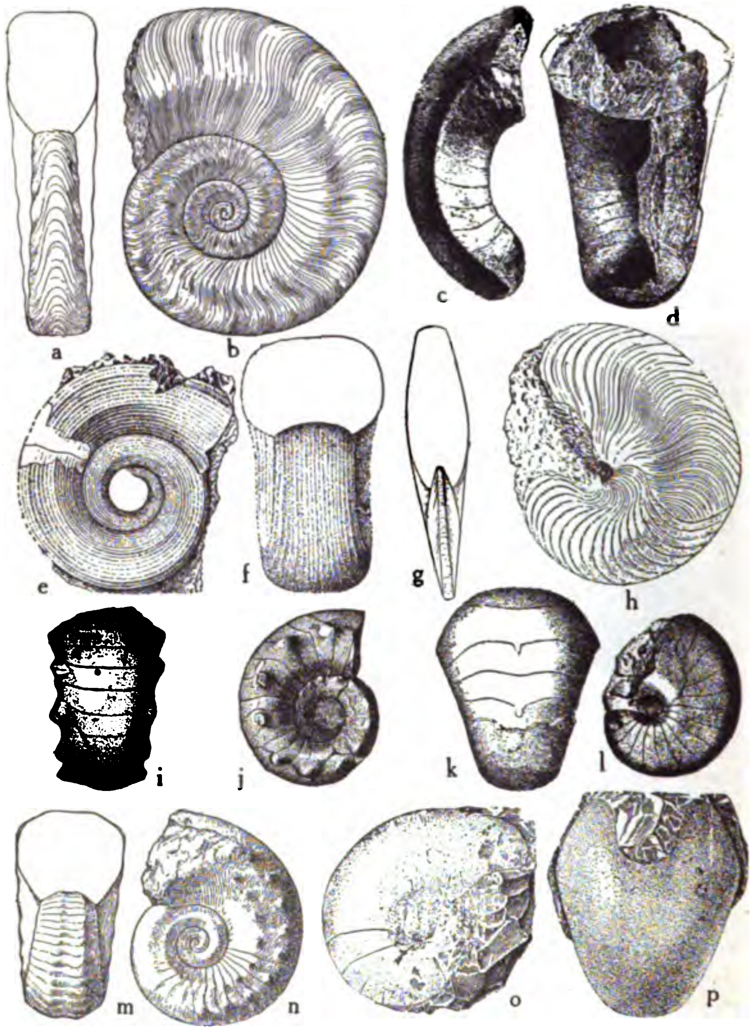


FIG. 1516. — Mississippian and Carbonic nautiloids. *a–b*, *Metacoceras walcotti*, × ½, Carbonic of Texas; *c–d*, *Edaphoceras niotense*, × ½, part of whorl; Keokuk of Illinois; *e–f*, *Thrincoceras depressum*, × ½, Carbonic of Kentucky; *g–h*, *Phacoceras dumblii*, × ½, Carbonic of Kansas; *i–j*, *Temnocheilus forbesianus*, × ½, Carbonic of Central and Southern States; *k–l*, *Solenocheilus collectus*, two individuals, × ½, St. Louis limestone, Ind., Ill., etc., Carbonic of Texas; *m–n*, *Tainoceras cavatum*, × ½, Carbonic of Texas; *o–p*, *Stearoceras gibbosum*, × ½, Carbonic of Texas. Note the varying degrees of involution and the variations in form.

Let us next assume that a coiled tube, divided at intervals by septa, is completely filled with mud which hardens to stone, the hardened mud thus filling the air-chambers between the septa. Breaking away the outer shell, the filling of stone would become visible, divided by the septa, of which only the edges which were in contact with the shell would be seen. If the edge of the septum was a smooth one, as in *Nautilus*, it would appear as a simple line or thin band encircling the stony filling of the interior. If the edge was fluted, this encircling band would exhibit these flutings. In the stony casts of cephalopod shells, these visible edges of the septa are called sutures and in the *Nautilus* they are simple (Figs. 1515, 1516). When they show a series of simple folds or flutings the type is designated a *Goniatite* (Fig. 1382) and it is these which first arose from the *Nautilus* type in Devonian time, after the manner outlined. In the Mississippian some of these became more complicated, secondary flutings forming on the backward-bending lobes (Fig. 1416). This is called the *Ceratite* type, and though it arose in the Mississippian and Pennsylvanian it did not become the dominant type until the Triassic (Fig. 1601). Finally in the Permian, and even earlier, a still more complex type arose where the forward-bending parts of the suture — the saddles — also developed secondary flutings. This constitutes the ammonite type (Figs. 1451–1453) and it became the dominant one in Jurassic time (Figs. 1658–1672). It is probable that these specialized types led a pelagic life, and so could survive the great changes which formed so potent a factor in the wholesale extermination of life at the end of the Palæozoic.

FIG. 1517. — A Middle Cambrian trilobite, *Marrella splendens*, dorsal view, illustrating the segments of the body, carapace, and its great posterior spines. Burgess shale, British Columbia. (After Walcott.)

a', antennule; *a''*, antennæ; *ab*, abdomen; *m*, third appendage-mandible; *c*, carapace, ×4.

Trilobites. — Of all Palæozoic animals these are the most unique, for they have left no descendants in post-Palæozoic time, though other classes have survived, such as the insects to which they apparently gave rise in the Palæozoic. In the oldest Palæozoic strata trilobites are already represented by many diverse and highly organized types; hence we must conclude that these animals had a long pre-Palæozoic history which is unknown because the marine rocks of the earlier periods have not yet been discovered. These animals had their maximum development in the Cambrian (Figs. 1019–1030, 1517–1519) (13 families) and Ordovician (Figs. 1067, 1068, 1137, 1138) (22 families), after which they steadily declined until in the Pennsylvanian only five genera, all of one family, remained, and only one (*Phillipsia*, Fig. 1383) continued into the Permian. Of the three orders of the trilobites two (Hypoparia, Opisthoparia) arose in pre-Cambrian time, and one (Proparia) in the Ordovician.

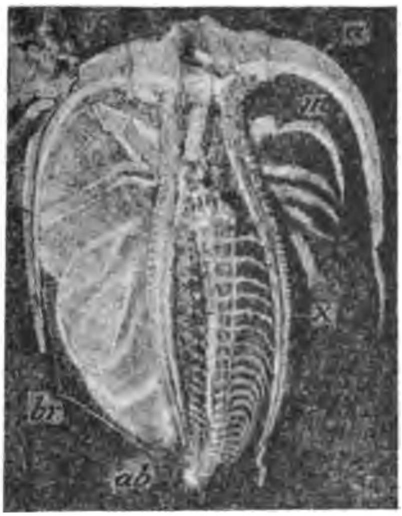


FIG. 1518. — *Marrella splendens.* Ventral view of another specimen, showing large gill lobes (*br*) (epipodites); *ab*, abdomen; *x*, posterior spine or lobe of carapace; *a′*, antennule; *m*, mandible (×4). Middle Cambrian, Burgess shale, British Columbia. (After Walcott.)

Other Crustacea. — The division of the Branchiopods (including Phyllopods), so called because their legs are leaf-like (gill-like) in form, and which are represented by the modern genus *Apus* (Fig. 925, p. 144), appears to be a very old one and is regarded by high authorities as ancestral to trilobites and other crustacea as well. These forms live to-day mainly in fresh water or in brackish or salt lakes, and this may have been true of many of the earlier ones as well. They are naked or covered by a horny carapace of one or more pieces. There are several genera in the Cambrian and Ordovician, where they appear to have been marine (Figs. 1520–1523). In the Devonian and later Palæozoic occur freshwater forms, of types which continue into the Trias (*Estheria*, Figs. 1335 *e*, 1421 *g*, *h*, 1607) and even into the Pleistocene.

The division of the Ostracoda differs from the preceding, in that the whole body is inclosed in a horny or calcareous shell instead

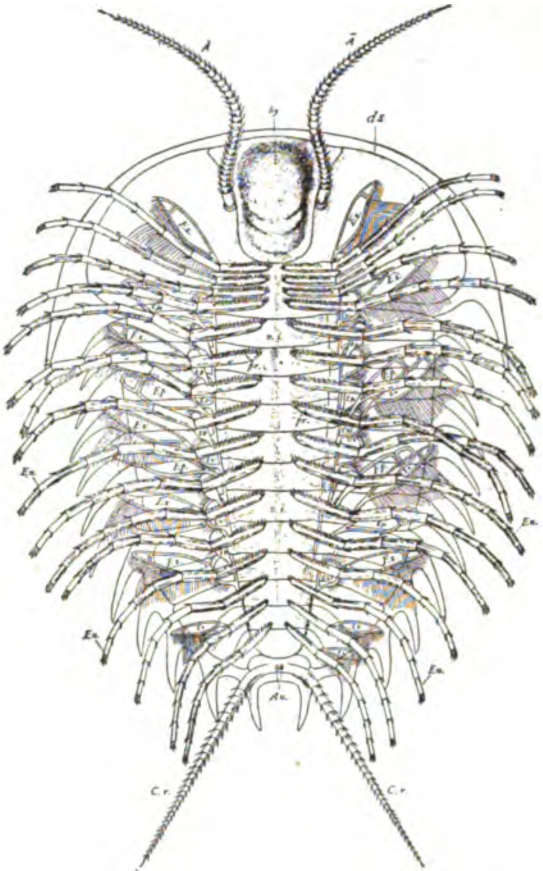


FIG. 1519. — Restoration of the under side of a trilobite (*Neolenus serratus*, Middle Cambrian), showing the appendages. (After Walcott.)

ds, dorsal shield; *hy*, upper lip or hypostome; *A*, antennules; *An*, anal aperture; *C.r.*, caudal spines or rami; *En.*, inner branches (endopodites) of walking legs; *Ex.*, outer branches (exopodites) of walking legs; *pr.*, basal joint of leg from which the two branches endopodite (*en*) and exopodite (*ex*) arise; *v.i.*, ventral covering or integument; *Ep.*, gill or branchia (epipodite).

of only the anterior part. They appear to have their first undoubted representation in the Lower Ordovician and become very abundant in the Middle and Upper Ordovician. The prevailing

FIG. 1520. — *Waptia fieldensis.* A Middle Cambrian branchiopod crustacean. Dorsal view of a specimen flattened on shale (× 1.5). *c*, carapace; *e*, eye; *a*, antennæ; *thl*, thoracic legs; *cr*, caudal rami. Burgess shale, British Columbia. (After Walcott.)

FIG. 1521. — *Opabinia regalis.* A Middle Cambrian branchiopod crustacean, dorsal view, male, flattened on shale; *fp*, frontal appendage; *e*, eye; *ths*, thoracic somites; *i*, intestine; *ab*, abdominal segment. Burgess shale of Stephen formation, British Columbia. (After Walcott.)

FIG. 1522. — *Hymenocaris perfecta.* A Middle Cambrian branchiopod, × 2. Side view of right valve, showing form, abdomen, and appendages; *ad*, adductor muscle scar; *i*, intestine; *thl*, thoracic legs; *br*, gills. Burgess shale, British Columbia. (After Walcott.)

FIG. 1523. — *Leanchoilia superlata.* A Middle Cambrian branchiopod, side view, natural size; upper specimen *Hymenocaris perfecta*, dorsal view of a crushed specimen, natural size. Burgess shale, British Columbia. (After Walcott.)

types through the Silurian belong to the *Leperditia* and *Beyrichia* families (Figs. 1139, 1229, 1334). Toward the close of that period, the Leperditias disappear, while the Cyprid (Fig. 1384) family makes its appearance, and in the Pennsylvanian the family of the Cypridinidæ (Fig. 1418) is most characteristic. Ostracods continue to exist to the present time.

The Cirripedes or Barnacles are represented by peculiar types in the Palæozoic (*Lepidocoleus*, *Turrilepas*, *Strobilepis*, etc., Figs. 1524 *a*, *b*) more nearly related to the modern goose barnacle (*Lepas*, Fig. 929) than to the acorn barnacle (*Balanus*, Fig. 928). These begin mainly in the Tertiary, but there is one Devonian representative (*Protobalanus*) — though it is of doubtful affinity.

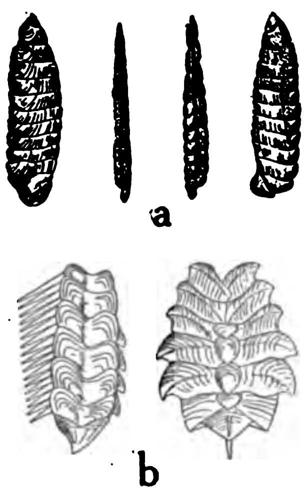


FIG. 1524 *a*, *b*. — Palæozoic barnacles or cirripedes (I. F.). *a*, *Lepidocoleus sarlii*, four views (×1½), Silurian (Niagaran); *b*, *Strobilepsis spinigera*, side and dorsal views, slightly reduced, Devonian (Hamilton).

The group of phyllocarid crustaceans is well represented in the Palæozoic deposits, where probably a number of them inhabited fresh or brackish waters, as is suggested by the nature of the strata in which they occur. Such are *Ceratiocaris* (Fig. 1525) of the Silurian waterlimes, and a number of forms from the Upper Devonian and the Pennsylvanian beds of eastern North America (Fig. 1421, p. 500). Truly marine forms, however, also occur in Palæozoic deposits.

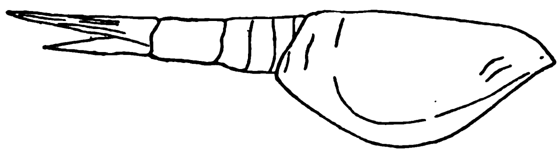


FIG. 1525. — A Silurian phyllocarid crustacean (*Ceratiocaris acuminata*) from the Bertie waterlime (upper Monroan) of Buffalo, N. Y. (×⅓). (I. F.)

True decapod crustacea, the order which includes lobsters, crayfish, and crabs, are unknown from the Palæozoic; but there are a number of primitive types of higher crustacea which occur in the Devonian and Pennsylvanian rocks, and probably include the

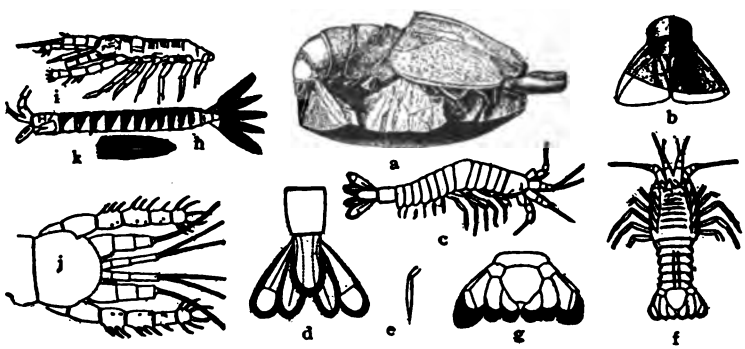


FIG. 1526. — Palæozoic schizopod (*a–g*) and amphipod (*h–k*) crustaceans. *a–b*, ***Palæopalæmon newberryi***, × ⅓, and caudal fin and last thoracic segment; Erie shale, Ohio, Kinderhook, Iowa. *c–e*, ***Palæocaris typus***, × 2, and caudal fin and single abdominal foot enlarged; Coal-measures, Illinois. *f–g*, ***Anthrapalæmon gracilis***, × ⅔ (upper surface of carapace removed) and caudal fin and last segments enlarged; Coal-measures, Illinois. *h–k*, ***Acanthotelson stimpsoni***, *h*, dorsal, *i*, side view, *j*, anterior portion enlarged, *k*, stylet of tail enlarged; Coal-measures, Illinois.

ancestral stock from which these higher forms were derived. In practically all cases, these occur in deposits believed to be of fresh-water origin (Fig. 1526).

Merostomata. — These remarkable crustacean-like animals were well represented in the Palæozoic, but mostly by fresh-water forms.

The eurypterids were the leading order, and these seem to have been throughout inhabitants of the rivers (Fig. 1230, p. 368). The same holds true for many of the members of the synxiphosurans (*Bunodes*, *Hemiaspis*, *Pseudoniscus*, Fig. 1230 *a*), and for some xiphosurians as well (*Belinurus*, *Prestwichia*, *Protolimulus*, etc., Fig. 1421 *a–d*). The modern representative of this last group, however, the horseshoe crab (*Limulus*, Fig. 937) is a marine organism. There were apparently also a number of marine Palæozoic merostomes, especially in the Cambrian (Figs. 1527–1530).

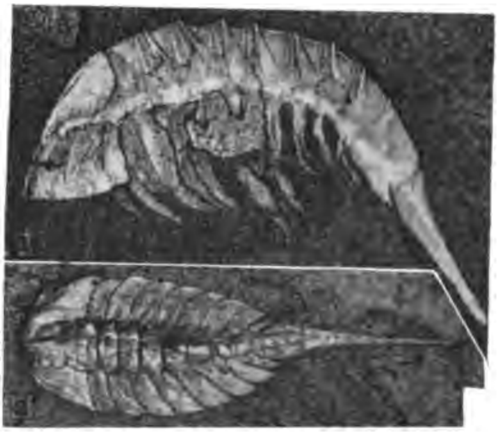


FIG. 1527 *a, b.* — *Molaria spinifera.* A Middle Cambrian merostome (Aglaspidæ), side and dorsal views (× 3). In the side view the thoracic pleuræ of the segments have been broken away so as to show appendages. Burgess shale, British Columbia. (After Walcott.)

Scorpions. — These land animals appear to have arisen from the eurypterids of the rivers in Mid-Silurian time, when the widespread withdrawal of the sea and the frequent drying up of the rivers under the arid conditions which prevailed, especially in North America, placed a premium on the ability to breathe air direct. Remains of the oldest known scorpions are found in beds of Upper Silurian age, both in North America and in Europe (Figs. 935 *a*, 1231), and in some cases they follow immediately upon the hiatus which represents the Middle Silurian interval. It is possible that the Silurian scorpions were still able to breathe in water, as structures similar to the gill-bearing appendages of the eurypterids occur. But the later Palæozoic scorpions, like the modern ones, were undoubtedly air-breathers, slit-like openings or stigmata in the abdomen admitting the air to the lung books. The acme of development of the scorpions seems to have been in the Pennsylvanian, after which the order declined (Fig. 1531 *a–c*).

Spiders, etc. — These appear first in the Coal-measure beds, where they had a considerable number of representatives. There

FIG. 1528. — *Emeraldella brocki.* A Middle Cambrian merostome; specimen flattened, giving partial view of head and body and a fine profile view of the abdomen and telson (× 2). *e*, eye; *a'*, antenna; *mx'*, maxillula; *mx''*, maxilla; *thl*, thoracic legs; *i*, alimentary canal. Burgess shale, British Columbia. (After Walcott.)

are also several orders of spider-like animals which are confined to the Palæozoic (Fig. 1531 *d–e*).

Myriapods. — Centipedes and thousand-legs are known from the Old Red Sandstone of Scotland (Devonian) and are common

FIG. 1529. — Middle Cambrian merostome of the order Limularva. *Sidneyia inexpectans*. Large dorsal shield, flattened and somewhat broken. An antenna projects on each side in front of the eye, and on the right is probably the fourth cephalo-thoracic appendage, pushed back under the second segment of the abdomen (× $\frac{4}{5}$). Stephen formation (*Ogygopsis* shale), Mt. Stephen, British Columbia. (After Walcott.)

in the Coal-measure strata, where they are known to attain the length of 20 cm. (Fig. 1532).

Insects. — These are abundant in the Coal-measure and Permian strata of North America and Europe (Fig. 1533), but their origin probably dates from an earlier period. Remains of insects have been reported from Ordovician strata of Europe, but there seems to be doubt regarding the authenticity of this reported occurrence.

FIG. 1530. — *Sidneyia inexpectans.* Enlargement of under side of a small cephalo-thorax with antennæ and four pairs of appendages and a portion of epistoma preserved ($\times$ 2.7). Middle Cambrian (Stephen shale), Mt. Stephen, British Columbia. (After Walcott.)

It is held by high authorities that the insects probably arose from some trilobite-like crustacean, and the most available type for such an ancestry seems to be the genus *Æglina* of the Ordovician.

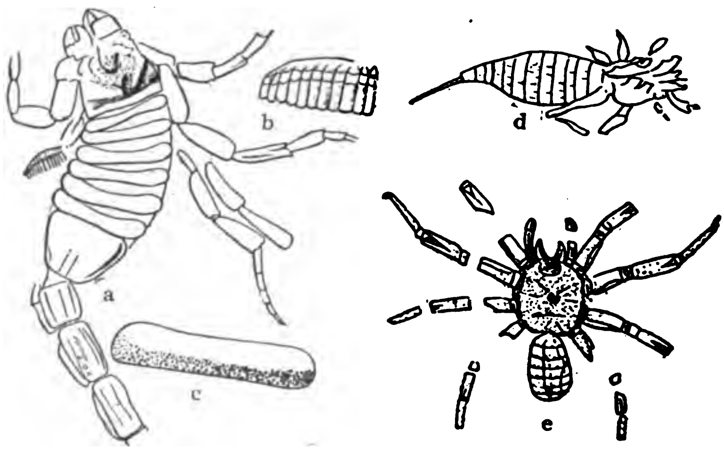
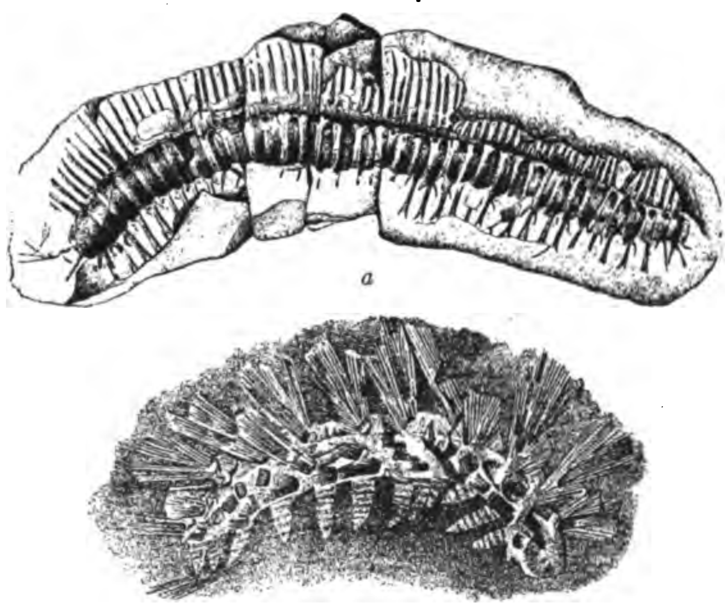


FIG. 1531. — Palæozoic (Carbonic) scorpion (*a–c*) and spiders (*d–e*). *a–c*, *Eoscorpius carbonarius*, nearly entire individual ($\times \frac{1}{3}$); *b*, comb (pecten) enlarged; *c*, body segment enlarged; Coal-measures, Illinois. *d*, *Geralinura carbonaria* ($\times$1), Mazon Creek, Illinois; *e*, *Arthrolycosa antiqua* ($\times$1), Mazon Creek, Ill. (I. F.)

It is possible that the mid-Ordovician period of sea-withdrawal, recognized in America and Europe (St. Peter emergence, p. 273), may have been the one during which this development of air-breathing types took place from the marine trilobites.

Worms.—Owing to the general absence of hard parts, worms leave only occasional indications of their presence where peculiar physical conditions permitted the preservation of the soft parts or impressions, as in the Cambrian of British Columbia (Figs. 1534, 1535).



a

b

FIG. 1532. — *Palæozoic* (Carbonic) myriapods (centipedes and "thousand legs"). *a*, *Palæocampa anthrax* (× 2), showing legs and bristles, Mazon Creek; *b*, *Acantherpestes major*, an almost complete individual; legs on upper and bristles on lower side of specimen (× ½). (Mazon Creek, Illinois.)

Sometimes, too, their castings are preserved with sufficient distinctness to permit of their recognition, although these are more often found in younger formations (Fig. 768). The trails and burrows of shallow-water worms are much more frequently preserved even in the oldest rocks (*Planolites*, Fig. 985, p. 188, pre-Cambrian; *Eophyton*, Fig. 1018, p. 231, Lower Cambrian; *Scolithus*, Fig. 762, p. 43, Upper Cambrian, etc.). The tube-building worms are abundantly represented by the minute coiled shells known as *Spirorbis* (Fig.

1536), and the annulated tubes known as *Cornulites*, *Conchicolites*, etc. (Fig. 1537). The minute horny plates and toothed structures, which are called, collectively, "conodonts" and which are believed

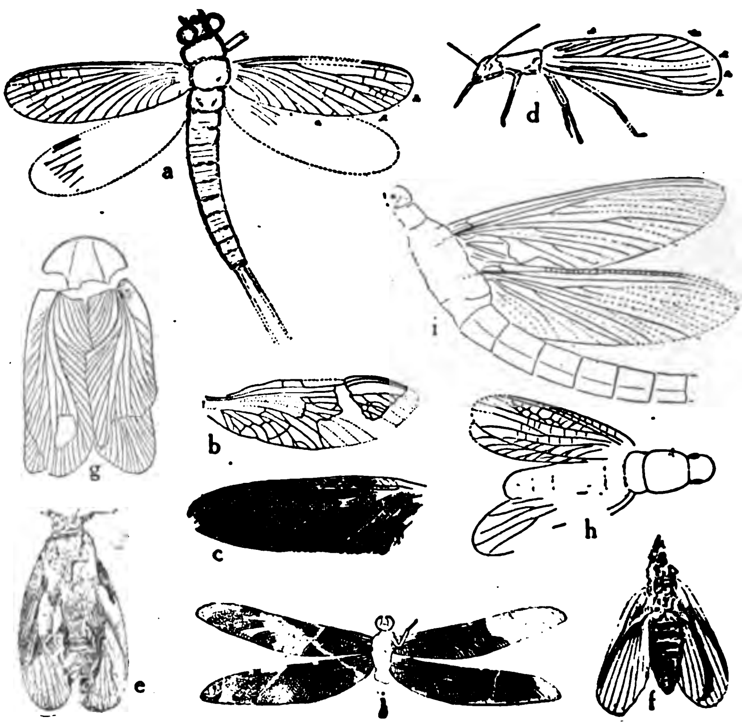


FIG. 1533. — Palæozoic (Carbonic and Permian) insects of North America. *a–c*, *Palæodictyoptera* (*a*, *Eubleptus danielsi* (× 2), Mazon Creek, Illinois; *b*, *Homothetus fossilis*, wing (× ¾), Little River group, New Brunswick; *c*, *Paolia vetusta*, wing (× ½), Mansfield sandstone of Indiana); *d*, *Protorthoptera*, locusts, etc. (*Gyrophlebia longicollis* (× ¾), Mazon Creek, Illinois (see also Fig. 1422)); *e*, *f*, *Protoblattoidea* or archaic cockroaches (*e*, *Eucænus ovalis* (× 1), Mazon Creek, Illinois; *f*, *Adiphlebia lacoana* (× ¾), Mazon Creek, Illinois); *g*, *Blattoidea* or true cockroaches (*Asemoblatta mazona* (× ½), Mazon Creek, Illinois); *h*, *Hadentomoidea* (*Hadentomum americanum* (× 1), Mazon Creek, Illinois); *i*, *Plectopora* or may-flies (*Protereisma permianum* (× 2), Permian of Kansas); *j*, *Protodonata* or dragon-flies (*Tupus permianus* (× ½), Permian of Kansas). (I. F.)

to be the œsophageal teeth of annelids, abound in several of the black shales of the Palæozoic, notably the Upper Ordovician and the Upper Devonian (Fig. 1335, p. 432).

FIG. 1534. — *Canadia setigera*. A slightly contracted specimen (×3) of a Middle Cambrian worm, showing parapodia and bundles of setæ. Burgess shale, British Columbia. (After Walcott.)

FIG. 1535. — *Canadia spinosa*. Middle Cambrian worm (×2). Dorsal view showing setæ and bundles of projecting ventral setæ, also head and tentacles. Burgess shale, British Columbia. (After Walcott.)

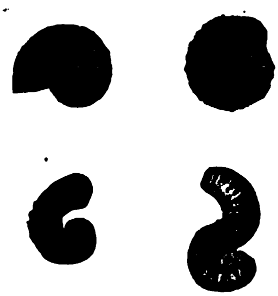


FIG. 1536. — Coiled worm tubes of the Palæozoic (*Spirorbis laxus*, Upper Silurian). (I. F.)

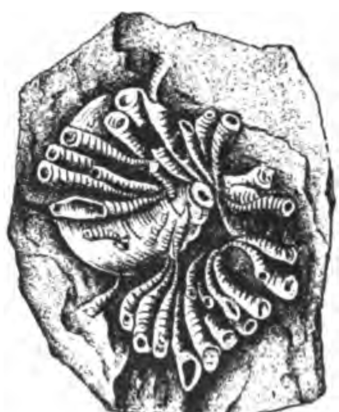


FIG. 1537. — A cluster of Palæozoic worm tubes (*Conchicolites corrugatus*) attached to a shell. Upper Ordovician, Ohio. (I. F.)

Echinoderms. — Of the three great divisions of this phylum — the Pelmatozoa, Asterozoa, and Echinozoa (Figs. 944–963, pp. 155–166), the first is most abundantly represented in the Palæozoic, while the other two have their ancestry there, but the acme of their development belongs to a later period. The Pelmatozoa, or stemmed echinoids, comprise three classes. The cystoids appear first in the Cambrian and attain their maximum in the Ordovician and Silurian, where more than 200 species are known, while only a dozen species occur in the Devonian, Mississippian, and Pennsylvanian, where they become entirely extinct. The blastoids appear first in the Ordovician, reach their acme in the Devonian and Mississippian, and have their last representatives in the Permian. The crinoids also make their first appearance in the Ordovician and become exceedingly abundant during the remainder of the Palæozoic, especially in the Devonian and Mississippian. (Fig. 1538; see also Fig. 1233, p. 369, Figs. 1328, 1329, p. 430, Figs. 1385, 1386, pp. 469, 470.) Of the four great orders into which this class is divided, three (Camerata, Flexibilia, and Inadunata) are practically confined to the Palæozoic, only one family having a Triassic representative (*Encrinus*, Fig. 1600). The fourth group (the Articulata), on the other hand, has no Palæozoic members, but is well represented from the Jurassic on. In the modern sea twenty families and nine additional subfamilies of this group are found, with about 100 genera and 650 species. Of these, 580 species belonging to 85 genera are unstalked forms (comatulids, Fig. 944), and these are the dominant types to-day. The modern stalked crinoids live in deep water, but the Palæozoic

FIG. 1538. — Restoration of an Upper Devonian crinoid in its natural habitat. From the model in the New York State Museum at Albany. (After J. M. Clarke.)

species were probably all shallow-water forms, judging from the character of the rock in which they occur.

a b

FIG. 1539, *a*, *b*. — *Palæaster eucharis*. *a*, Dorsal side of a specimen; *b*, view of the ventral side. (After Hall.)

Starfish appear first in the Upper Cambrian or Lower Ordovician (Tremadoc), and a number of primitive forms are known from the Silurian, Devonian, and later Palæozoic beds (Figs. 1539–1541), but

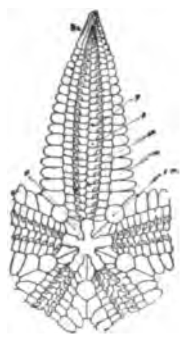


FIG. 1540. — *Palæaster eucharis*. Diagram of portion of ventral side with four of the arms incomplete. (After Hall.)

The ambulacral plates in the center have each only a single groove for the extrusion of the tubed feet, instead of two as in most modern forms. (See Fig. 955 *b*, p. 162.) The young plates, at the apex of the arms in the modern form, have, however, only a single groove. (*a*, ambulacral plate; *p*, the pore; *aa*, adambulacral plate; *m*, marginal plate; *tm*, terminal plate of the marginal series; *o*, oral plates, of which there are five pairs.)

the greatest development of these animals falls in post-Palæozoic time. Brittle stars (Ophiuroidea) also appear in the Ordovician and occur likewise in other Palæozoic horizons (Fig. 1542). They are, however, most extensively developed in the modern seas.

The sea urchins (Echinoidea), which form one class of the Echinozoa, have their oldest known representative in the Ordovician of Esthonia (*Bothriocidaris*, Fig. 1543). Several types occur in the Silurian and the Devonian, a larger number in the

Fig. 1541. — Restoration of an Upper Devonian starfish, in its natural habitat. From the model in the New York State Museum at Albany. (After J. M. Clarke.)

Mississippian, and fewer in the Pennsylvanian and Permian. Only four orders of echinoids are found in the Palæozoic. Of these one is confined to the Ordovician, being represented only by the primitive genus *Bothriocidaris*, another, with two genera (*Palæodiscus*, and *Echinocystis*, Fig. 1544), to the Silurian, while one order (Perischoëchinoidea) ranges from the Silurian to the Permian. This order is characterized by having mostly very many columns of plates in each area (two to twenty in each ambulacral, and three to fourteen in each inter-ambulacral area), and it is wholly confined to the Palæozoic (examples: *Palæechinus*, Fig. 1545; *Melonites*,

FIG. 1542. — A Palæozoic (Mississippian) brittle-star (*Onychaster flexilis*), Keokuk, Indiana.

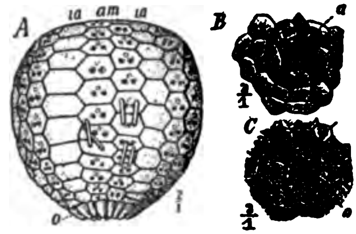


FIG. 1543. — *Bothriocidaris pahleni.* An Ordovician echinoid. *A*, restored individual twice enlarged; *am*, ambulacral area of two columns of plates; *ia*, interambulacral areas, consisting of only one column of plates. *B*, plates of upper surface surrounding anal aperture (*a*); *C*, plates of lower surface, surrounding oral aperture (*o*). (From Steinmann.)

Fig. 1388 *i*, p. 472). Only one order, that of the Cidarida, begins in the Devonian or Mississippian and continues with increasing numbers through the Mesozoic and Tertiary to the present time.

Holothurians, or sea cucumbers, apparently lived throughout the Palæozoic, but their remains are rarely well preserved, being

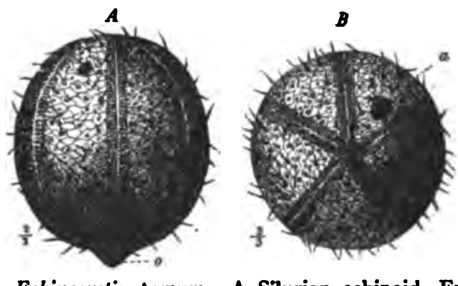


FIG. 1544. — *Echinocystis pomum.* A Silurian echinoid, England. *A*, *B*, restored individual lateral and summit views, two-thirds natural size; *a*, anal aperture; *b*, oral aperture. (From Steinmann.)

represented chiefly by their scattered plates. In the Middle Cambrian strata of British Columbia, however, some wonderfully preserved forms have been found, retaining many details of

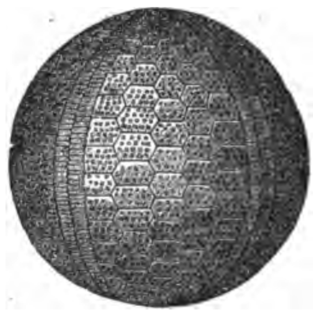


FIG. 1545. — *Palæechinus elegans*. Mississippian, Ireland. (From Steinmann.)

FIG. 1546. — Middle Cambrian holothurian, *Mackenzia costalis*. A small individual showing the mouth. Natural size. Burgess shale, British Columbia. (After Walcott.)

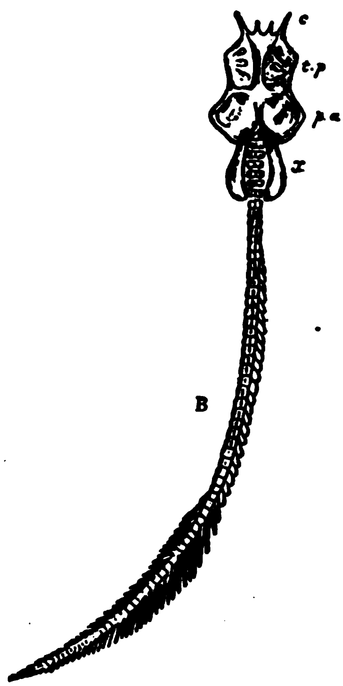


FIG. 1547. — Reconstruction of the skeleton of *Palæospondylus gunni*, a primitive cyclostomous fish. Head from ventral side showing: *c*, cirri; *pa*, auditory capsule; *tp*, nasal region; *x*, post occipital appendages. Lower Devonian, Old Red Sandstone, Caithness, Scotland. (After Traquair.) Enlarged about four and a half times.

the soft parts (Fig. 1546). Most of these are allied to forms existing to-day in the deep oceans.

Fishes and Ostracoderms. — The earliest Palæozoic fish types (ostracoderms) yet discovered occur in the Harding sandstone of the Rocky Mountain Front Range in Colorado and Wyoming. This sandstone represents the St. Peter horizon, being the outwash from the old western land-mass (Rockymontana) during the retreatal phases of the Lower Ordovician (Beekmantown), and as such it is primarily a continental formation, though partly reworked

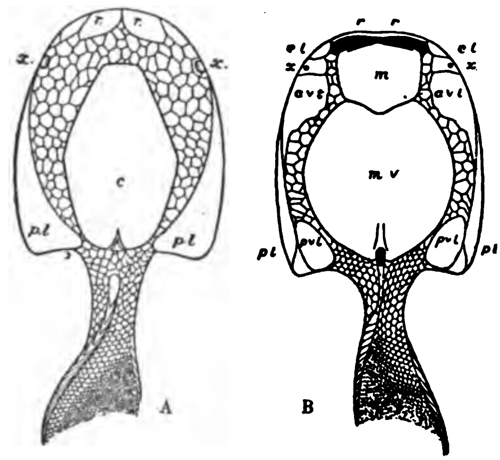


FIG. 1548. — Reconstruction of *Drepanaspis gemündensis*, a heterostracous ostracoderm or primitive fish-type.

A, dorsal side; *B*, ventral side; *avl*, anterior ventro-lateral plate; *c*, median dorsal plate; *el*, external labial plate; *m*, head plate; *mv*, median ventral body plate; *pl*, posterior lateral plates; *pvl*, posterior ventro-lateral plates; *r*, rostrum; *x*, orbital plates. Lower Devonian, Bundenbach, Eifel, Germany. (After Traquair.) About one-fourth natural size.

by the readvancing later sea. The presence of the fish remains, much comminuted, in this sandstone and their absence from the normal marine strata both above and below, indicates that these organisms were not living in the sea, but in the rivers which washed out the sands over the emerging sea-bottom.

The American Silurian contains several species of ostracoderms and true fishes. A few fragmentary spines have been found in marine strata, whither they might easily have been transported, but the best preserved specimens are found in sandstones which indicate at least a shoaling and probably a considerable retreat of the sea and outwash of sands by rivers. In Europe, too, fish occur in the Upper Silurian (Ludlow), where in the midst of terrigenous strata actual fish-beds (bone-beds), practically composed of the remains of these organisms, eurypterids, etc., are found. These are interpreted as representing estuaries into which the fish from the rivers entered and where, owing to an advance of the salt water from the sea, they were abruptly killed in vast numbers. Fish

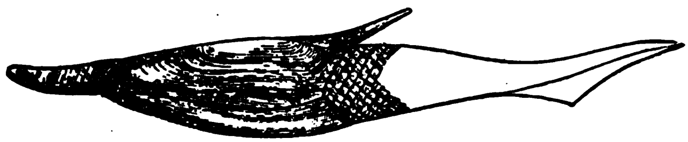


FIG. 1549. — Reconstruction of *Pteraspis rostrata*, a heterostracous ostracoderm; side view, about one-third natural size. Lowest Old Red Sandstone (Passage beds), Herefordshire, England. (After Woodward.)

remains are practically absent from the normal marine strata of this period, but are abundant in the continental deposits transitional to the Old Red Sandstone, and in that formation as well, which is recognized as a typical continental, in large part river flood-plain, formation. In the marine Devonian only the shagreen granules of the ostracoderms have been found, but the entire armor of individuals occurs in the Old Red Sandstone (Figs. 1547–1550). In North America, too, the great river deposits or alluvial fans and

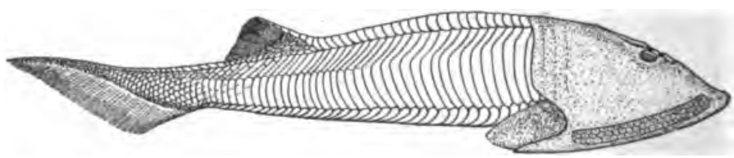


FIG. 1550. — Reconstruction of *Cephalaspis lyelli*, an aspidocephalous ostracoderm, about five-twelfths natural size. Lower Devonian, Old Red Sandstone, Forfarshire, Scotland. (After Stromer.) (See Fig. 1344, p. 435.)

deltas of the Devonian contain wonderfully preserved remains of the ostracoderms, especially in the Gaspé sandstone series, the Catskill, and the continental Elbert formation of Colorado (see Fig. 1293, p. 408). The ostracoderms died out by the end of the Devonian. In America, at least, they appear to have been restricted to the torrential rivers, none occurring in the deposits of the rivers from the southern flat and black-soil-covered region.

In the Middle Devonian marine limestones of Europe and America are found many remains of fishes, especially those of *Dipterus* (Fig. 1342, p. 435), a member of the lung-fish or dipnoan division. These remains are, however, only fragmentary, consisting of spines, teeth, and other parts, while perfectly preserved complete individuals are found only in the river-deposits (Old Red Sandstone). The same thing is true of the arthrodire genus *Coccosteus* (Fig. 1343) which is plentifully represented by fragments and plates in the marine Devonian limestones, while complete individuals are known only from the Old Red Sandstone of Scotland. A fairly complete series of plates has also been obtained from the Chemung sandstone of Pennsylvania, a deposit formed at the edge of the Catskill delta. From this it might be argued that these fish still lived primarily in the rivers but occasionally entered the sea. On the whole, however, the arthrodires were not common in the rivers of Appalachia, but this group is abundantly represented in the deposits of the mud-bearing rivers from Mississippia, in which the remains of

FIG. 1551. — Reconstruction of *Rhinosteus traquairi* (× ½), an Upper Devonian armored fish (arthrodire). Germany. (Jaekel.)

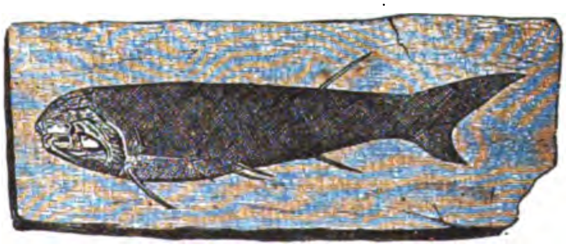


FIG. 1552. — *Acanthodes mitchelli*, an acanthodian shark, natural size. Lower Devonian, Old Red Sandstone, Farnell, Scotland. (After Egerton.)

11 genera are embedded, some of them of gigantic size (*Dinichthys*, Fig. 1296, *Titanichthys*, etc.). One of the small forms is shown in Fig. 1551. Being heavily armored, they probably were not very active swimmers, leading primarily a bottom existence.

The spine-bearing or acanthodian sharks appeared first in the

Silurian, but were especially characteristic of the deposits formed by the rivers of Appalachia in Devonian time, and they continued in the Mississippian and Pennsylvanian. Sharks became very abundant in the later Palæozoic, some 300 species being known from Mississippian strata, but before the end of the Palæozoic this number had been greatly reduced. The Devonian genus

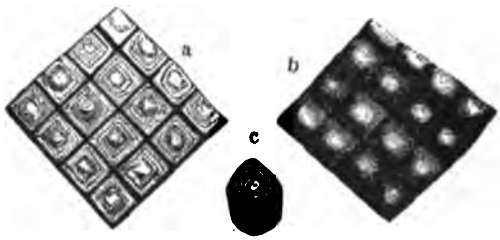


FIG. 1553. — Enlarged scales of *Acanthodes gracilis*. *a*, Outside; *b*, inside; *c*, isolated scale. Permian (Rothliegendes). (From Zittel.)

Acanthodes (Figs. 1552, 1553) still occurs in the Rothliegendes of the Permian. The crossopterygian or fringed-finned ganoids of North America seem to have been chiefly restricted to the deposits of Appalachian rivers and are common in the Old Red Sandstone of Europe as well, the most common and widespread form being *Holoptychius* (Fig. 1340, p. 434). These ganoids reached their acme

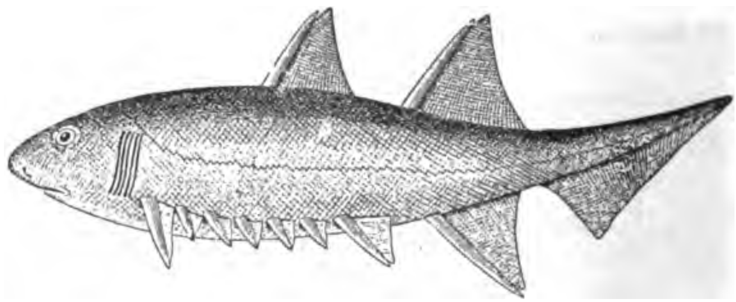


FIG. 1554. — Reconstruction of *Climatius macnicoli*, an acanthodian shark from the Devonian, Old Red Sandstone, Scotland. (After Woodward.)

of development in the Devonian and are remarkable for their limb-like fins, their conical, generally fluted teeth, and their covering of rhomboidal or rounded scales. These fish have been thought to be in the line of ancestry of the amphibians, but the characters which are suggestive of amphibian affinities may be due to parallel development rather than relationship. The actinopterygians, or true ganoids, appear to have existed in Devonian time in the torrential rivers of Appalachia and Atlantica, and in the muddy rivers of Mississippia and other regions as well, but they were generally different generic types. This order is most characteristic of the Pennsylvanian deposits, and the two common fish of the Kupferschiefer at the base of the Zechstein of northern Europe (*Palæoniscus* and *Platysomus*, Figs. 1429, 1430, pp. 512, 513) belong to this order. They were again enormously abundant in the muddy deposits of Triassic rivers and equally so in the Jurassic, and are represented in the modern fauna (Gar-pike).

Altogether, the Palæozoic waters were rich in fish of varied and often archaic types, many of which disappeared toward the end of the Palæozoic, though a few, such as the typical ganoids and the sharks, continued to flourish in the Mesozoic. No true bony fishes (Teleostei) existed, however. These appear first in the Mesozoic and have become the dominant fish type to-day.

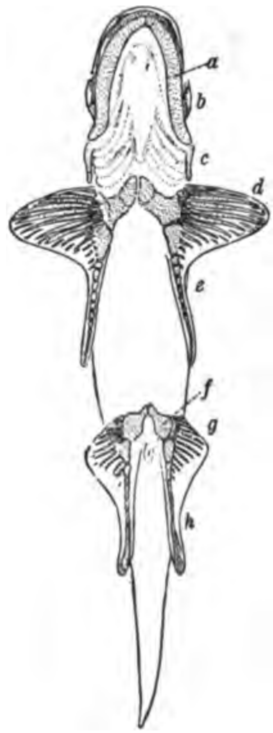


FIG. 1555. — Reconstruction of the ventral side of *Cladoselache fyleri*, a pleuropterygian shark; one-sixth natural size.

a, Mandible; *b*, eyes; *c*, gill arches; *d*, pectoral fins with long, articulated axis *e*; *f*, pelvis; *g*, anal fins with long, articulated axis *h*. Upper Devonian (Cleveland shales), Ohio. (After Jaekel.)

Amphibians. — Probably the greatest event in the history of Palæozoic life was the appearance of land vertebrates. There is abundant reason for believing that the earliest land vertebrates, the amphibians, arose from fishes which inhabited the Devonian rivers and which in their own structure had already approached somewhat that of the higher vertebrates. This is especially true of the crossopterygian ganoids in which, as we have seen, the horny structure of the fins approaches more nearly to that of the vertebrate limb than is the case in any other fish type. The modern crossopterygian, *Polypterus* (Fig. 969), which lives in the rivers of Africa, often remains motionless for a long time on the bottom of the river, the anterior part of the body resting upon the tips of the pectoral fins. Its air bladder is an accessory respiratory organ, supplementing the gills, and this fish is able to live out of water for three or four hours at a time, when covered with damp grass or weeds.

In the Upper Devonian deposits occurs a crossopterygian ganoid (*Sauripterus taylori*), the forward or pectoral fins of which have a structure approaching more nearly to that of the primitive limb-structure of land vertebrates than is the case in any other type. Indeed many of the bones of the leg of the amphibia are represented in the fin of this fish, though additional ones exist in the fins, which disappear in the transformation into the limb, while at the same time others develop. But the modification is such as could readily be conceived, without undue stretch of the imagination, as capable of accomplishment.

FIG. 1556. — Reconstruction of *Cheirolepis trailli*, a heterocercal ganoid (about one-fourth natural size). Lower Old Red Sandstone, Middle Devonian, Scotland. (From Jaekel.)

The oldest known amphibian foot-print has been obtained from the Upper Devonian Chemung rocks of Pennsylvania. This foot-print of an unknown animal, called *Thinopus antiquus* (Fig. 1345), is very primitive, having only two fully developed fingers together with the rudiment of the third and the suggestion of the fourth digit. This budding of the later digits from the outside of the second one is characteristic of the development of the foot of the modern salamander, and it thus appears that in *Thinopus* we have a primitive foot stage which antedated the development of the five-toed foot so characteristic of typical land animals.

Foot-prints of amphibians also occur in the Lower Mississippian continental beds of Nova Scotia, and in the Mauch Chunk beds of Pennsylvania and Virginia. These foot-prints indicate that the full number of five toes had been developed at that time.

In the Mississippian (Lower Carboniferous) of Scotland (Edinburgh Coal-measures), there have been found the earliest skeletal remains of amphibians so far obtained. They represent already fully developed amphibians, and are therefore well along the line of evolution of the class. Higher rocks again contain foot-prints. In general, foot-prints alone occur in the red rocks which indicate relatively dry climate under which bones would soon disintegrate. In the deposits of a more pluvial climate, on the other hand, the bones became buried and were preserved.

Amphibia lay their eggs in water and the young lead for a while a fish-like existence, breathing by means of gills and swimming by the aid of a well-developed tail. This is familiar to us in the developmental history of the frog, which in the young or tadpole stage is as truly an aquatic gill-breathing animal as any fish (Fig. 972, p. 170). In the second season of its existence, when legs have begun to appear, the animal comes to the surface to breathe air and finally, losing its gills and tail, it lives permanently on land. It then breathes air into its lungs through the mouth, and returns to the water only to lay its eggs and to hibernate, but never again to breathe like a fish.

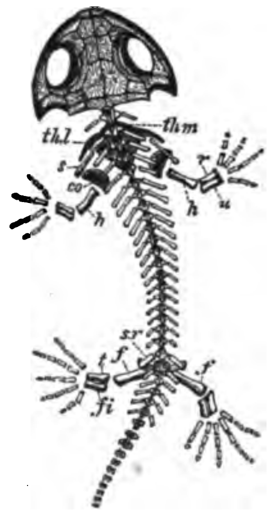


FIG. 1557.—Larval form of *Branchiosaurus amblystomus* from the Rothliegendes near Dresden, natural size. (From Steinmann.)

co, Coracoid; *f*, femur; *fi*, fibula; *h*, humerus; *r*, radius; *s*, scapula; *sr*, sacral ribs; *t*, tibia; *th. l*, lateral thoracic plate; *th. m*, median thoracic plate; *u*, ulna. (Gills present in this stage, omitted.)

It is easy to see that an increase in the aridity of the climate, with accompanying long seasons of drought when waters would dry away and vegetation perish, would result in placing a premium on the ability to assume an air-breathing habitat, and it is this climatic change, more than any other cause, that probably brought about the development of the amphibian from the fish type. The necessity of better adaptation for locomotion upon the dry land, once this mode of life had been assumed, would tend toward the modification of the swimming fin into the ambulatory limb. Now just such climatic changes were going on in late Devonian and in Mississippian time, and it was the stress of these increasingly adverse conditions of existence, which, though it sounded the death-knell of thousands that could not adapt themselves to the change, forced those few, which were possessed of innate tendencies to modification, to rise to higher levels of existence. They thus became the progenitors of those vast races of air-breathing organisms which were destined to dominate the world in future ages, and from

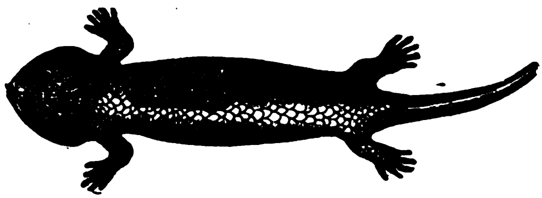


FIG. 1558. — A Permo-Carbonic stegocephalian of the suborder Sauromorpha (*Ricnodon copii*), Bohemia. Restored, three-fifths natural size. (After Fritsch, from Steinmann.)

which at last, still under duress of prodding climatic and other physical conditions, arose the human type, the crowning achievement of the play of natural forces on the plastic living world.

The Palæozoic amphibia varied greatly in form and size, — some were snake-like, others resembled modern salamanders, and still

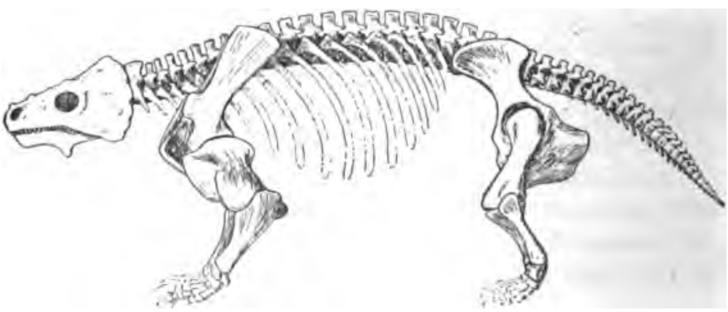


FIG. 1559. — Restoration of one of the oldest, most primitive reptiles (*Pareiasaurus serridens*) from the Middle Permian Karoo formation of South Africa. (After Broom.)

The skeleton is from eight to nine feet long and stands about three and one-half feet high. This form is interesting because it shows certain mammalian characteristics, such as the well-developed, powerful limbs, and the position of the body high above the ground instead of near to the ground as in modern reptiles.

others had a crocodile-like form with large, often grotesque, heads. In length they ranged from less than an inch to about eight feet. Generally two pairs of limbs were present, with four toes on the fore and five on the hind limbs, and a well-developed tail. The upper part of the head and the anterior part of the body of many forms were covered with thick, often highly sculptured bony plates, on which account these animals are classed together as *Stegocephalia*, or animals with an armored or mailed head. Others, however, had their entire body covered with small overlapping scales, while in still others these were confined to the ventral or under side of the body. In this respect they differed markedly from modern amphibians which, with rare exception, have naked skins.

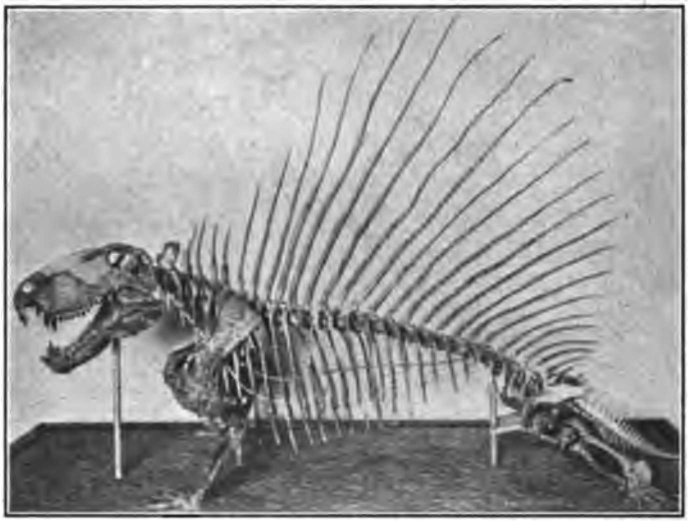


FIG. 1560. — The skeleton of the fin-back reptile (*Dimetrodon gigas*). (After Gilmore.)

This animal was probably the dominant type in the American Permian, reaching a length of from six to seven feet and a height of about five feet. It crawled along the ground much as modern reptiles do, and in all likelihood lived along the borders of pools and swamps, feeding upon the smaller reptiles and amphibians of the time. The striking spines which formed a crest along the back were elongations of the vertebræ and were apparently of little use to the animal, being rather a hindrance to locomotion. (Specimen mounted in U. S. National Museum.)

The stegocephalians were characteristic of the lands of late Palæozoic time and continued through the Triassic, after which they disappeared. Even in the Palæozoic, however, some of their species had given rise to the class of reptiles which is represented at first by forms so nearly allied to the stegocephalian that it is often difficult to determine in which class they should be placed.

The tooth structure, too, of one of the groups of Palæozoic amphibians was highly involved, the dentine of the large conical teeth being infolded in a most complicated labyrinthine fashion, on which account the name *Labyrinthodonts* has been applied to them (p. 501).

Some of the more characteristic types of late Palæozoic amphibians are illustrated in the figures (Figs. 1557, 1558, and 1565).

Reptiles. — Before the close of the Palæozoic the class of reptiles also had made its appearance. These animals differ from amphibians in the absence of the gill-breathing larval stage, the direct air-breathing young, and in the egg, which is laid on land instead of in the water and is provided with a porous shell beneath which is a sac-like membrane, the allantois, plentifully supplied

FIG. 1561. — Restoration of the fin-back lizard, *Dimetrodon gigas*. (After Gilmore.)

with blood vessels from the embryo. The oxygen of the air enters through the shell and passes by osmosis through the membrane of the allantois and oxygenates the blood, while at the same time carbonic acid is given off and passes outward. Such an interchange of gases is best carried on in a dry climate, and it is possible that were the egg submerged in water the embryo would drown. Thus reptiles can develop in regions devoid of water, and indeed many modern forms live in deserts. This leads to the supposition that it was the increasing aridity of the climate which influenced the full development of these characters by preserving those forms in which a tendency in this direction had appeared. Or again it may be that those forms whose eggs had become modified so

FIG. 1562. — The skeleton of a Permian fin-back reptile, *Naosaurus*, a contemporary of *Dimetrodon*, having, however, more ornate spines with cross-bars developed at frequent intervals along each spine. From the Permian of Texas. (Courtesy of the American Museum of Natural History.)

that they finally could develop out of water were enabled to wander away from the well-watered lowland, the regions to which the amphibians were confined, and penetrate the arid upland dis-

FIG. 1563. — Restoration of the Permian fin-back reptiles *Naosaurus* (in foreground) and *Dimetrodon* (in background). (Courtesy of the American Museum of Natural History.)

tricts where under stress of adverse conditions they became rapidly more and more modified.

Reptiles are already represented in the Pennsylvanian by highly specialized types, so that it appears that this class probably arose in Mississippian time. These reptiles still bore many points of resemblance to their amphibian ancestors, but there was in general a tendency toward reduction in the size of the skull and loss of

FIG. 1564 *a*. — Skull of a Permo-Triassic thereidont reptile (*Galesaurus planiceps*) from South Africa; lateral view.

a, Eye; *n*, nasal; *s*, temporal bone; *f*, frontal; *fa*, præfrontal; *im*, intermaxillary; *j*, jugal; *mx*, maxillary; *n*, nasal; *p*, parietal; *c*, canines; *i*, incisors; *m*, molars. (After Steinmann.)

FIG. 1564 *b*. — Skull of a Permo-Triassic thereidont reptile (*Lycosaurus curvimola*) from South Africa; lateral view, one-fourth natural size; *q*, quadrate bone. (After Steinmann.)

the body armor. The feet terminated in five fingers and toes. The later Palæozoic reptiles are generally divided into three groups as follows:

1. *Cotylosaurs*. — These were the most primitive of the class and retained many ancestral stegocephalian characters, such as the covering of the skull by sculptured plates, the large median or pineal eye, so characteristic of the stegocephalians, the occasional presence of body armor, etc. Though mostly small, at least one form (African) reached a length of over 9 feet. They were slow crawlers but apparently good swimmers, and their habits of feeding were for the most part carnivorous. They are known to range from late Pennsylvanian through Triassic time. One of the Palæozoic types is shown in Fig. 1559.

FIG. 1564 *c*. — Skull of a Permo-Triassic thereidont reptile (*Trilylodon longævus*), Karoo formation, South Africa. Upper jaw, three-fourths natural size. (From Steinman.)

2. *Pelycosaurs*. — These represented a more specialized and active type of Palæozoic reptiles. They were carnivorous land animals, more or less lizard-like in form, some attaining a length of 8 feet. Among them some peculiar modifications had arisen which in-

dicate that specialization in many of these forms had already gone to extremes. Such was the case in the peculiar fin-back lizards (*Dimetrodon* and *Naosaurus*, Figs. 1560–1563), in which a series of spines arose from the backbone, which probably supported a membranous skin to form a high fin extending from the head to the base of the tail. The pelycosaurs were most characteristic of North America, though they had representatives in Europe as well, appearing in Upper Pennsylvanian time. They, too, ranged through the Triassic.

3. *Thereodonts.* — This was a group of South African reptiles existing in Permian and Triassic time (Karoo formation). They were remarkable in that their teeth, instead of being essentially of uniform character throughout, as in typical reptiles, were differentiated into incisors, canines, and molars, as in mammals. It is thought that this group may have given rise to the primitive mammal. The skulls of several of these animals are illustrated in Figs. 1564 *a–c*.

FIG. 1565. — Restoration of a late Carbonic or early Permian landscape in the Texas region. The swampy borders of a sluggish creek are shown with the giant *Calamites* rising up from the water on the right, while on the land, in the background, are the branching *lepidodendrons* and the unbranched *sigillarias*. Over the water skims a dragon-fly, with a wing-spread of nearly two feet; in the creek is a theromorph reptile (*Limnoscelis*), while on the land are two of the ancient stegocephalian amphibians (*Eryops*) which attained a length of about seven feet. (After Williston.)

CHAPTER XLI

THE TRIASSIC, FIRST OF THE MESOZOIC SYSTEMS

THE formations now grouped together under the Mesozoic division were among the first of the stratified rocks with which geologists became familiar. In the Saxon-Bohemian mountains, which early became the object of geological study because of their important minerals and ores, these formations rest directly upon the crystalline rocks, the Primitive or primary division of the older geologists (see p. 6). On this account they were called *Secondary* rocks, and because of their usual horizontal position they were designated *Flötz-gebirge* or Flötz-formations by the miners. The name *Mesozoic* was given to this series of formations in comparatively recent times, because the organic remains which they contain were recognized as representing the mediæval period in the development of life upon the earth.

These Mesozoic rocks were first studied in greatest detail in England, where they form for the most part a series of alternating hard and soft strata of nearly horizontal position, except in a few localities where they have been folded. They begin with the great New Red Sandstone, which lies as a rule upon disturbed older beds, and end with the Chalk. Between these lie the oölitic limestones or Oölites, and these and the Chalk form the two prominent ridges or cuesta-fronts which extend across central England, while the valley between them is formed by the softer green-sands and clays (Gault). A clayey or shaly series (the Lias) also lies below the Oölites, and out of this and the New Red Sandstone, the large valley or inner lowland, west of the Oölite cuesta, is carved (see Fig. 739, p. 10). The general relationship of these strata is shown in the following section across central England (Fig. 1566).

Such an arrangement naturally led to a threefold division of the Mesozoic rocks, the Chalk with the green-sands and clays below it being classed as the *Cretaceous series* (from *creta—chalk*). It naturally fell into an Upper (chalk) and Lower Cretaceous (green-sand, Gault, etc., see further Chapter XLIII), a division borne out more or less fully by the organisms present in these strata. The Oölites were found to have a wide distribution over western Europe,

FIG. 1566. — Diagrammatic section across England from Gloucester on the west to Swindon on the east, showing the succession of Mesozoic formations. *a*, Triassic; *b–g*, Jurassic (*b*, Lias; *c*, Lower Oölites; *d*, Oxford Clay; *e*, Corallian; *f*, Kimmeridge Clay; *g*, Portland and Purbeck beds); *h*, Cretaceous (Chalk). (From Lake and Rastall, *Text-book of Geology*.)

forming important limestones in the Jura Mountains, on which account the system which they represent was named the *Jurassic system*.

The lowest member of the Mesozoic trinity became the *Triassic system* (see below) and thus the subdivision of the old Secondary rocks, or the Mesozoic series, became the following:

3. *Cretaceous* { Upper Cretaceous or Cretaceous proper = Cretacic
Lower Cretaceous or Comanchean = Comanchic
2. *Jurassic*
1. *Triassic*

The lowest of these, the Triassic, will be considered in this chapter.

ORIGIN OF THE NAME TRIASSIC

As we have seen, the system now called Triassic is essentially a unit of red sandstone, shales, and conglomerates in England, where it is known as the New Red Sandstone, though in this group were originally included some sandstones of similar character now known to belong to the Permian. In northern Germany, on the other hand, the basal Secondary or *Flötz-gebirge* was known even in the days of Lehmann, Füchsel, and Werner (p. 25, Pt. I), *i.e.*, in the later part of the eighteenth century, as including two sharply separable and important basal members which had been designated the *Bunter Sandstein* and the *Muschelkalk*, respectively. Later, in the early part of the nineteenth century (1820), the clays and sands overlying the *Muschelkalk* proper were separated by Leopold von Buch and others under the name *Keuper*, derived from the Coburg region, and in 1834 the Swabian geologist von Alberti combined these three formations under the name *Trias*, in contradistinction to the underlying *Dyas*, the twofold series now called Permian. Thus gradually the name *Triassic* came into use for this oldest of the Mesozoic systems.

The threefold division found in Germany is, however, not characteristic of other parts of the earth, where the system is largely represented by limestones as is the case in the Alps and in the Mediterranean region generally. Here the facts call for a division into six groups, one of which is generally considered as representing the *Bunter*, two, the *Muschelkalk*, and three, the *Keuper*. This is the normal marine facies, and it has become the standard of comparison for other parts of the world.

In North America the red sandstones and basaltic flows and intrusives found in the Connecticut Valley, in the Palisade region on the Hudson, and elsewhere, were early recognized as younger than the Palæozoic rocks, and referred either to the Triassic or to the Jura-Trias. They are now known to represent only the *Keuper* division of the Germanic Trias. In the western United States similar red sandstones are widespread, especially in the Rocky Mountains, and these have generally been designated by the term *red beds*, and referred to the Triassic or to the combined Jura-Trias. It is now known that many of these red beds belong to the late Palæozoic (Permian or even Pennsylvanian), though the higher members of the red bed series represent the Triassic.

Marine Triassic strata of the Alpine type are well developed in western North America, and their character and fossil contents have gradually been made known, especially by the labors of Martin and others in Alaska, of Hyatt, Diller, and especially of J. P. Smith in California, Nevada, and other western states, and of Carlos Burckhardt and others in Mexico.

Relation of the Triassic to the Older Rocks

The rocks of the Triassic system, the first of the Mesozoic, are separated from those of the Palæozoic in practically all parts of the earth by a hiatus or break in sedimentation, though this break is not very apparent in those regions where both the last of the Palæozoic and the first of the Mesozoic are continental beds, as in the *Karoo* formation of Africa. It has been assumed that in at least one locality in India the succession from the Palæozoic to

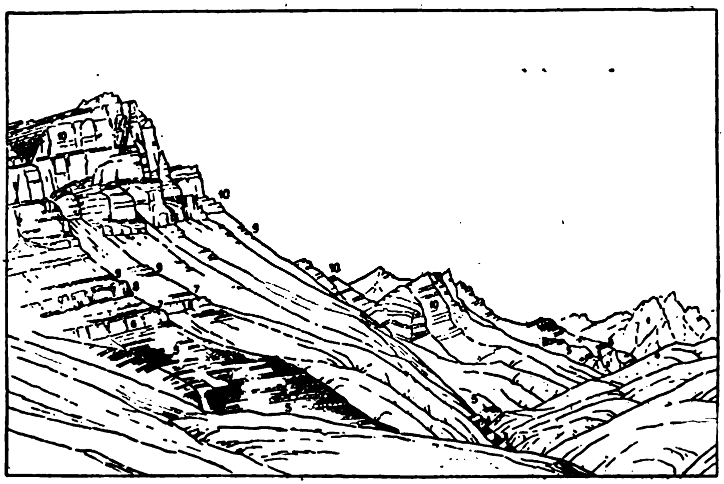


FIG. 1567. — Cliff of Shal-Shal, near Rimkin Paiar, Himalaya Mts. (After C. Diener.) Altitude between 4700 and 5700 meters. 1, Older Palæozoic; 2, Carbonic quartzites; 3, beds with *Productus* and Lower Triassic fossils (*Otoceras woodwardi*, Fig. 1568); 4–10, Triassic beds (4, Virglorien; 5, *Daonella* beds; 6, *Hauerites* beds; 7, *Halorites* beds; 8, beds with *Spiriferina griesbachi*; 9, *Sagenites* beds; 10, massive limestones (Rhætic)).

the Mesozoic is complete, the earliest marine deposits of the Triassic following immediately above the last marine beds of the Permian. In the Himalayas (Fig. 1567), beds with *Productus* and Lower Triassic fossils (*Otoceras woodwardi*, Fig. 1568) form apparently a transition series from the Palæozoic to the Mesozoic. More recently, however, doubt has been cast on the completeness of the Palæozoic series in that region, and it appears that even there a pronounced hiatus exists between the Permian and the Triassic.

FIG. 1568. — *Otoceras woodwardi*, an early Triassic ammonoid with ceratitic sutures. *A*, lateral; *B*, apertural views; *C*, suture (*el*, outer lobe; sl_1, sl_2, first and second lateral lobe; *es*, outer saddle; *ms*, median saddle; ss_1, ss_2, first and second lateral saddles). Lower Triassic, Shal-Shal Cliff, in the Himalayas. (From Steinmann.)

Interpreted in terms of palæogeography, this implies that the oceanic waters retreated from the continents at the close of Palæozoic time and did not return until some time later, when a new marine fauna had developed. It is probable, however, that in regions of continental sedimentation the interruption was not a pronounced one, and so we find, in some sections at least, such as those of South Africa already referred to, a more or less continuous series of ancient land animals of the late Palæozoic and the early Triassic period preserved in successive beds of what appears to be practically a uniform series. In general it may be said that the change in physical conditions and in area of deposition was more marked in North America, where the Palæozoic closed with the pronounced Appalachian and other disturbances, than it was in Europe, where the areas of deposition during early Mesozoic time remained essentially the same as those which received the late Palæozoic deposits.

Classification of the Triassic

The name Triassic, as already noted (p. 605), is derived from the threefold division of the system in North Germany where the deposits were first studied in detail. Here we meet with a marine intercalated between two continental series, though the upper one again becomes in part marine. This threefold division is as follows:

Upper Triassic or *Keuper* with *Rhætic* at the top (Keuperian)
Middle Triassic or *Muschelkalk* (marine) (Franconian)
Lower Triassic or *Bunter Sandstein* (Vosgian)

A more complex series of deposits occurs in the Alps and in the Mediterranean basin generally, where the following subdivisions are recognized which serve as a standard of comparison for the marine phase of the Triassic of other parts of the earth:

Upper Triassic	Rhætic Noric Karnic
Middle Triassic	Ladinic Anisic
Lower Triassic	Skytic

Though these divisions are important in detailed work, it will be sufficient for our purposes to use merely the threefold division into Lower, Middle, and Upper Triassic.

The Triassic System in North America

The Eastern Region. — We have seen that as the result of the folding of the strata of the Appalachian geosyncline, a new geosyncline came into existence to the east of the resulting mountains

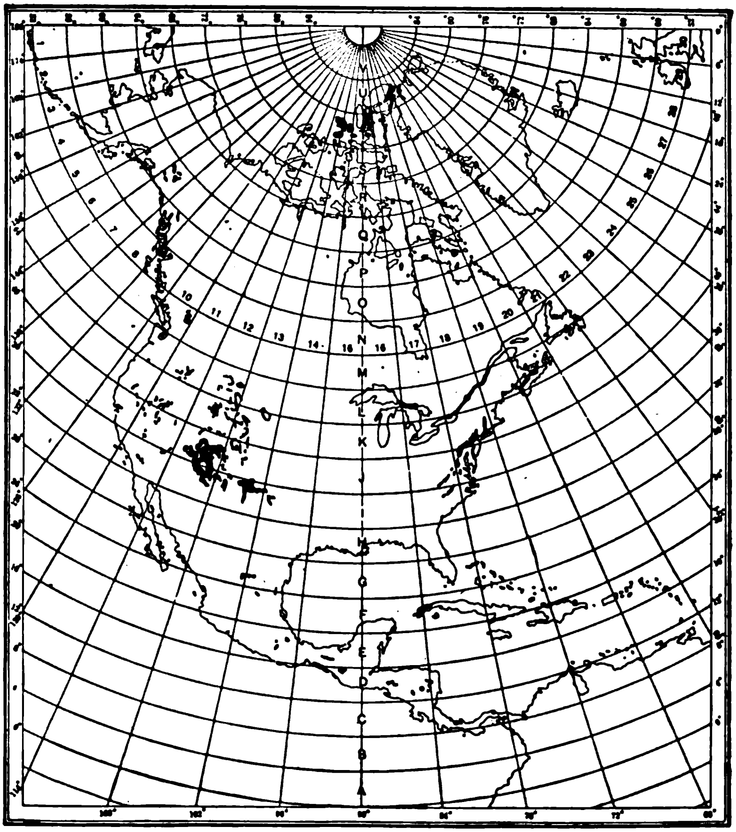


Fig. 1569. — Map showing the outcrops of Triassic rocks and of undivided Triassic and Jurassic rocks in North America. (After Bailey Willis.)

and upon the oldland of Appalachia. The full size of this geosyncline is undetermined, nor is it known to what extent it was separated from the Atlantic Ocean on the east. It may be that this ocean had access to the deeper part of the geosyncline, but if so this portion is now buried beneath younger coastal plain strata.

We know at present of no Lower or Middle Triassic in eastern North America, but beds of Upper Triassic age (Newark System) are found at intervals from Nova Scotia to South Carolina (Fig. 1569). They are entirely of continental origin, consisting of sandstones and shales, usually of a red color, of arkoses, and, locally, of conglomerates. The beds, which have a maximum thickness

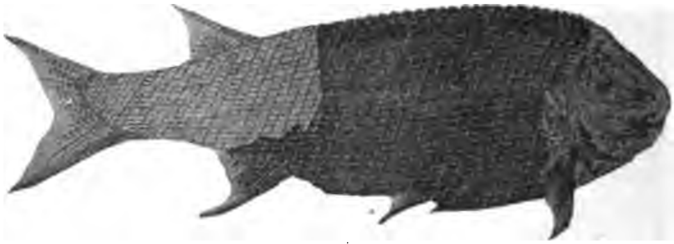


Fig. 1570. — *Catopterus redfieldi* from the black shales in the Triassic sandstone of the Connecticut Valley and New Jersey. (After Newberry.)

of 14,000 to 18,000 feet (including igneous members), abound in mud-cracks (Fig. 758, p. 40), rill-marks, clay-galls, raindrop impressions, the tracks of vertebrates (reptiles), and other evidence of river flood-plain and playa-lake deposition, while the more massive sandstones frequently show cross-bedding, either of torrential or of eolian type. In some sections the deposit is a heterogeneous mixture of ill-assorted boulders and sand, such as is known to form at the debouchure of heavily laden torrential streams along the margins of

Fig. 1571. — *Ischypterus micropterus* from the black shale in the Triassic sandstones of the Connecticut Valley. (After Newberry.)

desert basins. In the Connecticut Valley and in New Jersey and southward, these formations include beds of black shale in which the bodies of fish (ganoids) are wonderfully well preserved (Figs. 1570, 1571). These fish beds occur in at least two distinct horizons. In the southern areas (Virginia, North Carolina) beds of coal of considerable economic importance are included in this series of deposits, while associated with the coal and also occurring apart from it are the remains of plants indicative of Rhætic age. Thick beds of black shale, abounding in the shells of the little crustacean *Estheria* (Fig. 1607), also occur.

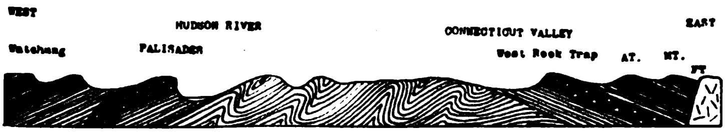


FIG. 1572. — Generalized cross-section from the Palisade region of New Jersey to the Connecticut Valley at New Haven, showing the complementary arrangement of the strata and lava sheets, suggesting that they may have been part of the same series arched and separated by erosion. The diagram is foreshortened and simplified. (For detail of Connecticut Valley region see Fig. 1580.) *AT*, Anterior trap (lava) sheet. *MT*, Main trap (lava) sheet. The West Rock trap is intruded, that of the Palisades trap is intruded, and that of the Watchung Mountains represents flows. *FT*, fault. (Original.)

Igneous rocks, chiefly basalts, are very characteristic of these deposits in all the northern areas, occurring both as contemporaneous surface flows and as intruded sills, and more rarely as dikes. Imposing examples of the lava flows are found in the great basaltic masses which form the cliffs on the Bay of Fundy Coast of Nova

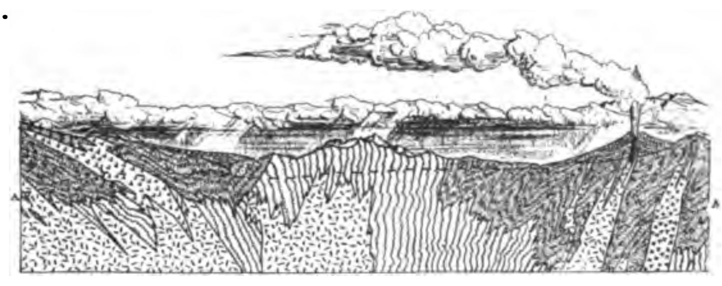


FIG. 1573. — The New England region during the late Palæozoic. The surface was mountainous, the Palæozoic strata and crystallines having been folded during the Taconic and Appalachian disturbances. (Barrell.)

Scotia and terminate on the north in Capes Blomidon and Split, and the magnificent cliffs of Cape d'Or (Figs. 449, p. 533 and 484, p. 577, Pt. I). Another splendid example is the great Holyoke diabase of the Connecticut Valley, a sheet 400 feet thick and 2 or 3 miles in width. Others are found in the Watchung

Mountains of New Jersey and in Pennsylvania. Beds of volcanic tuff and agglomerate are widespread.

A typical example of an intruded sill formed during this period of volcanicity is seen in the thick trap or diabase sheet which forms

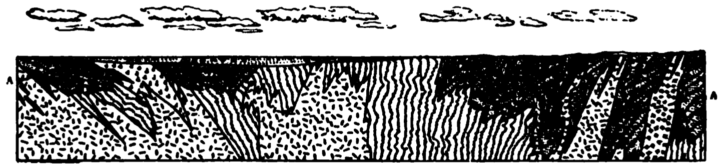


FIG. 1574. — Peneplanation occurred during the Lower and Middle Triassic. The beginning of Neo-Triassic time marked renewed sedimentation of a continental character upon the old peneplane. (Barrell.)

the Palisades of the Hudson (Fig. 140, p. 197, Pt. I), while a similar trap sheet occurs in the Connecticut Valley (Figs. 1572, 1580).

These continental Upper Triassic deposits are to-day distributed in a series of isolated patches along the Atlantic border, the three

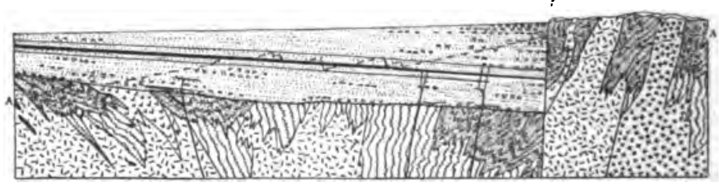


FIG. 1575. — Completion of Upper Triassic (Newark) sedimentation in the Connecticut region; lava flows and intruded sheets in black. (Barrell.)

largest lying in western Nova Scotia, the Connecticut Valley area, and the New York-New Jersey-Pennsylvania area. These and the other smaller areas of Virginia and North Carolina are mere erosion remnants of once much more extensive deposits. In many cases the remnants have been preserved by being faulted

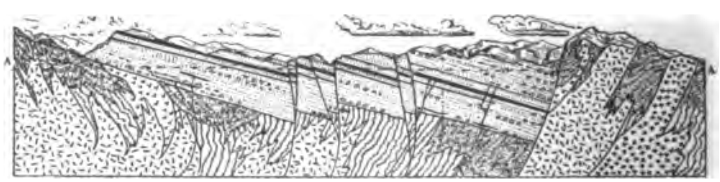


FIG. 1576. — Dislocation and block faulting affecting the Newark strata in Jurassic time. (Barrell.)

down beneath the level of erosion, which in post-Triassic time reduced this region to a peneplane.

It has been held that some of these deposits, notably those of the Connecticut Valley, were formed in depressions bounded by faults along which more or less movement was taking place during the deposition (Figs. 1575–1580). While probably true for certain

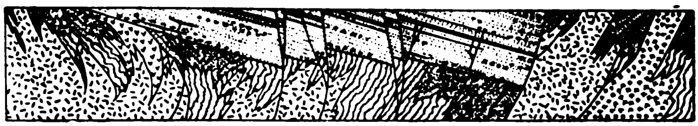


FIG. 1577. — The second peneplanation of the region, affecting the Newark deposits. Cretaceous time. (Barrell.)

sections, this is not always so. Indeed, in many places where the deposits abut against a fault-plane, the material in the sediment differs from that composing the wall-rock, whereas, if this fault represented a growing cliff during the accumulation of the sediment at its base, there should be a large amount of material derived directly from this cliff itself, as is indeed the case in some sections. From this and other arguments we conclude that many and perhaps most of the faults are of post-Triassic (probably

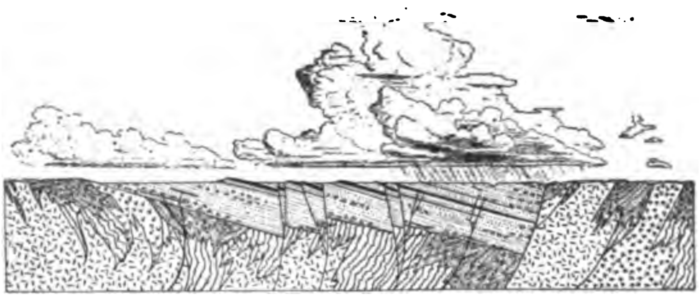


FIG. 1578. — Renewal of valley cutting. Carving of valleys on softer strata. Close of Tertiary time. (Barrell.)

Jurassic) origin. The igneous intrusions and surface flows, as well as the tuff beds, indicate that volcanism was active throughout later Triassic time in eastern North America, and a part of the faulting may have accompanied the volcanic manifestations. Not infrequently the lava-flows seem to have covered bodies of shallow, standing water, or overspread a flood-plain deposit still saturated with water. In such cases the base of the lava sheet was rendered porous by the resulting steam, while sand and mud was not infrequently carried up into the lava-sheet for some distance by the

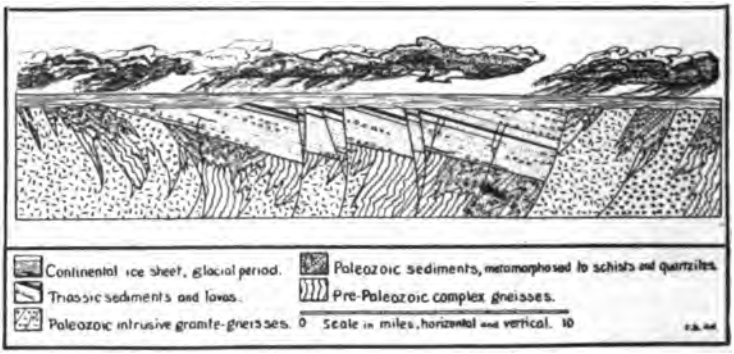


FIG. 1579. — The Connecticut region during the Glacial period. (Barrell.)

violent activities of the expanding steam. Subsequently the cavities in the lava-sheet were filled with mineral matter, forming geodes and pockets lined with crystals of amethyst, etc., or more or less filled with a great variety of zeolitic and other minerals.

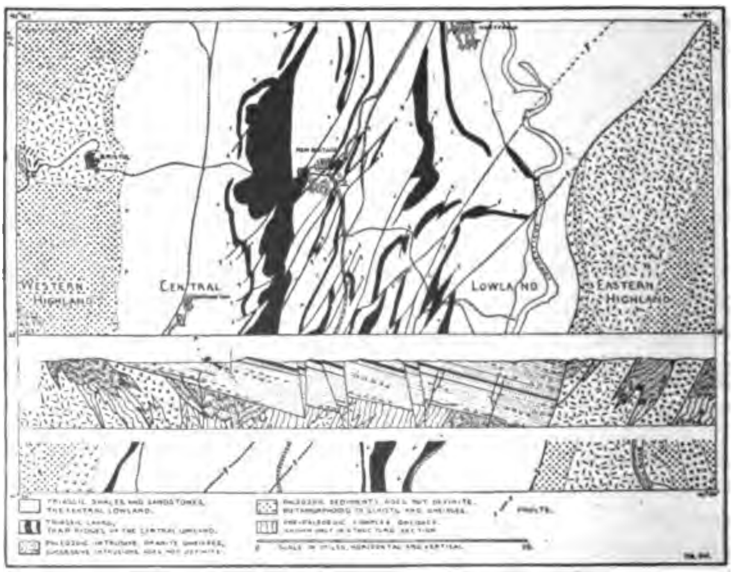


FIG. 1580. — Map and section of the Connecticut Valley region (Newark deposits) as existing to-day. (Barrell.)

Famous deposits of such minerals are found in the basal portion of the Nova Scotia mass, and in that of New Jersey (Paterson region).

So far as it is possible to determine, the great mass of material which is comprised in these continental deposits of Triassic age is derived from the west, in large part from the erosion of the eastern folds of the Old Appalachian Mountains. The probable relationship is indicated in the following diagram (Fig. 1581). This relation holds true for the later Mesozoic deposits of this region as well, and is in striking contrast with the fact that

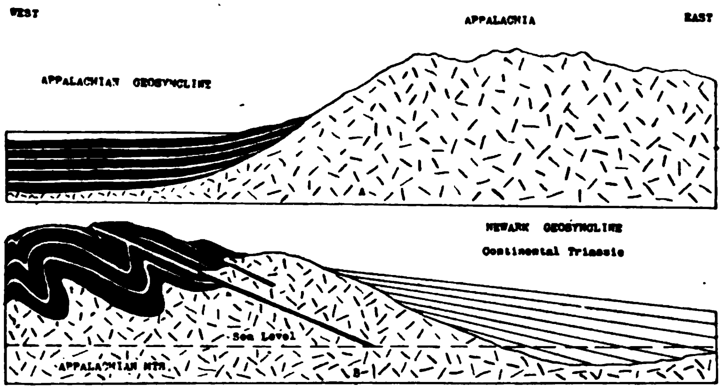


FIG. 1581. — Sections illustrating the eastward migration of the Appalachian geosyncline and the development of the Newark geosyncline. *a*, the Appalachian geosyncline of deposition as it existed to the end of Palæozoic time. The source of the clastic sediment was on the east in Appalachia. *b*, the Palæozoic sediments folded to form the Appalachian Mountains. The Newark geosyncline is formed by the subsidence of Appalachia. (Original.)

during Palæozoic time the great mass of sediment was derived from Appalachia on the east. Deposits of this type are principally formed on the leeward side of mountain-chains which are of sufficient height to deprive the winds of most of their moisture in crossing them. Therefore it would appear that the prevailing or planetary winds of the Mesozoic in this region were westerlies as they are to-day, whereas in Palæozoic time they were easterlies, such as are found farther south in this country at the present time. Such an inversion of the direction of prevailing winds is readily explained if we may assume a change in the position of the poles of the earth at the end of Palæozoic time, this change establishing essentially the conditions which exist to-day. However, until the possibility of such a pronounced rearrangement of the earth as a whole is shown by other facts, this explanation can be accepted only in a tentative manner. Nevertheless, it would be difficult to explain these changes by any purely local rearrangements of land and sea and of ocean-currents, such as are often appealed to.

Western North America. — In western North America, the stage setting for the development of the Triassic and Jurassic sequences of

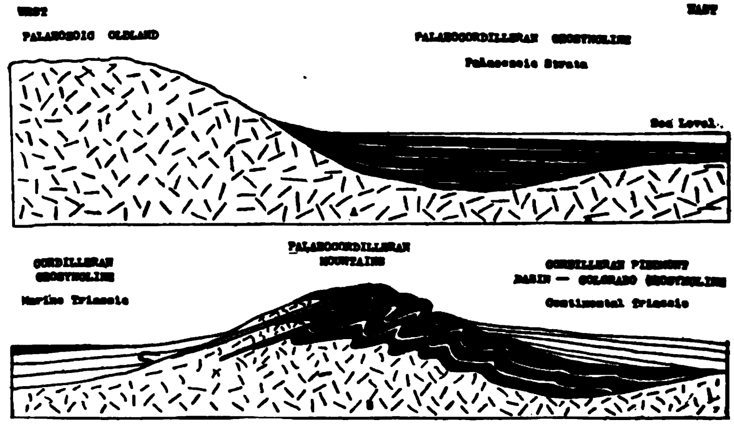


FIG. 1582. — Diagrammatic sections to illustrate the formation of the Palæocordilleran mountains and the Neo-cordilleran geosyncline and Piedmont basin. The Palæozoic strata were folded at the end of Palæozoic time, and two basins of deposition were formed, separated by these mountains. In the eastern one, continental sediments were the chief deposits, in the western, marine beds accumulated throughout Mesozoic time. (Original.)

events was produced by the formation of the Palæocordilleran Mountains through the folding of the Palæozoic strata which had been deposited in the Palæocordilleran geosyncline, and by the accompanying formation of the Cordilleran geosyncline to the west. As these mountain-foldings affected primarily the deeper portion of the old Palæocordilleran geosyncline in which the Palæozoic deposits were thickest, there remained a portion of that geosynclinal region, to the east of this new-formed mountain range, where the older strata were but little or not at all affected. The Triassic and Jurassic strata which accumulated in this more eastern region had essentially a concordant relation to the older sediments, though as the folded strata of the mountains were being worn down some of the younger beds also came to rest unconformably upon their eroded edges. We will speak of this eastern basin of deposition as the Cordilleran Piedmont basin or trough. West of the newly formed mountain chain lay the main Cordilleran geosyncline, formed upon the old crystallines, which furnished a large part of the material of the terrigenous beds of the Palæozoic. In this trough or geosyncline the Triassic beds rest, therefore, directly upon the pre-Palæozoic rocks. Whether there was any intercommunication between the western and eastern troughs around the northern end of the Palæocordilleran Mountains is as yet unknown, but the similarity of the faunas seems to suggest that such was the case. The relationships of these areas of deposition to each other and to the Palæocordilleran Mountains is shown in the preceding cross-sections (Fig. 1582).

Triassic Deposits in the Cordilleran Piedmont Basin

United States. — The southern part of this basin or trough, which extended into Arizona and New Mexico, was the site of continental sedimentation of material, derived in large part by erosion of the strata of the Palæocordilleran Mountains. Since these mountains lay in the path of the westerlies, or southwesterlies, and since they were apparently high enough effectively to deprive these winds of most of their moisture, the climate to the east of the mountains became arid, in consequence of which the deposits were thoroughly oxidized, and are now in large part red beds. These Triassic red beds rest in general conformably upon the Palæozoic in Arizona, New Mexico, Utah, Colorado, and elsewhere, and they are to-day exposed in the Colorado Plateau region and in the Front Ranges of the Rocky Mountains. In a few cases, as in the Grand River Valley sections, the contact between the Triassic (*Dolores*) and the Palæozoic beds shows a slight unconformity, the older beds dipping at a moderate angle, while the Triassic strata rest upon the eroded surfaces of various members of this older series. Here, then, is indicated a slight disturbance, probably a doming of the older strata at the time of the formation of the Palæocordilleran Mountains farther west. This disturbance was analogous to the formation of the domes and basins, and of the synclines and anticlines between them, in the eastern part of the continent during the Appalachian folding.

The general relationship of the Triassic strata of this region will be made clear by a comparison of two sections, one in the banks of the Little Colorado River, the other in the Ouray and Telluride districts of Colorado, to the northeast of the preceding (Fig. 1583). In both sections the Triassic beds lie upon Permian strata, the contact being a disconformable or even slightly unconformable one in the northeast, but apparently, though probably not actually,

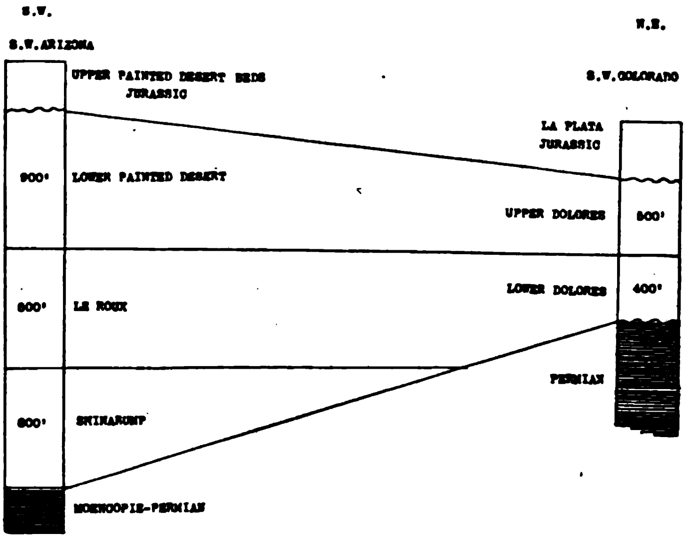


FIG. 1583. — A comparison of columnar sections of the Triassic beds of southwestern Arizona with those of southwestern Colorado. This shows the thinning and overlapping of the successive divisions of the Triassic, from the southwest to the northeast or away from the Palæo-cordilleran mountains, the source of supply of the clastic material. The Triassic beds rest disconformably upon continental Permian, and are disconformably succeeded by continental Jurassic. (Original.)

conformable in the southwest. In both cases the series begins with conglomerate beds and is followed by sands and clays, but there is an older series, the *Shinarump*, in the southwestern region which is absent in the northeastern section, where by overlap the lower Dolores, equivalent probably to the higher part only of the *Leroux* of the Arizona section, rests directly upon the Permian. The upper Dolores, which corresponds to the lower *Painted Desert* beds of the Little Colorado section, is probably incomplete, as there is an erosion interval between the Dolores and the La Plata (Jurassic).

As these deposits are all continental in origin and clearly derived from the southwest, it is evident that the overlap is away from the source of supply and is of the type characteristic of alluvial fans. The relationship of these strata at the time of their formation was therefore something like that shown in the following diagram (Fig. 1584. Compare also Figs. 382 *a–c*, pp. 465, 466, Pt. I).

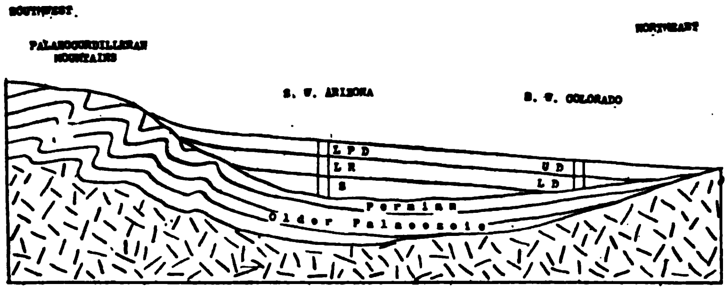


FIG. 1584. — Ideal section restoring the conditions in the Neo-cordilleran Piedmont Basin (Colorado geosyncline) in Triassic time. The locations of the sections in the diagram, Fig. 1583, are given. (Original.)

The Shinarump comprises conglomerates, coarse, often cross-bedded sandstones, and variegated marls. The conglomerates contain an abundance of fragments of silicified wood. The Leroux formation consists mainly of variegated argillaceous and calcareous marls, followed by sandstones, limestones with flint fragments, and at the top by more calcareous marls. In this series is found one of the famous petrified forests of Arizona, consisting of logs of wood which have become changed to agate (Fig. 1585). This wood represents the trees which probably grew on the higher slopes of the Palæo-cordilleran Mountains, from which they were washed down during heavy freshets and buried in the accumulating strata. Bones of crocodiles are also found here, and again in the equivalent lower Dolores beds to the northeast. These lower Dolores beds are composed of variable sandstones, limestone conglomerates, and shales, partly greenish or gray in color and persistently fossiliferous at certain horizons, the fossils being belodont crocodile remains and other reptiles. The bones are common in the conglomerates, where they are much worn. Occasionally fresh-water shells are found (*Unio*, *Vivipara*, *ante*, pp. 51, 52).

The lower Painted Desert beds of the Arizona sections begin with soft, friable, argillaceous sandstones of orange color (100 ft.) followed by variegated, brilliantly colored, and irregularly stratified sandstones (800 ft.). They are in turn followed by cross-bedded sandstones, probably of Jurassic age. The equivalent of this series in Colorado, where it is often removed by Jurassic erosion, is a fine shale of strong red color, and bands of massive sandstone, generally without cross-bedding, 20 or more feet in thickness, of fine and even grain.

While these continental beds were accumulating in the southern part of this basin, the northern part was invaded by the sea from the northwest, and there the strata were mainly of marine origin, as they are in the geosyncline to the west of the Palæocordilleran ranges. These strata are now found in parts of Idaho, Wyoming, and northern Utah, where they rest with apparent conformity (probably disconformably) upon the Permian beds, which here are

FIG. 1585. — Fossil logs in the Petrified Forest National Monument, Apache Co., Arizona. Triassic. (Department of the Interior.)

phosphate-bearing (Phosphoria formations). All these strata have been much deformed by post-Cretaceous disturbances.

The Triassic series begins with thin-bedded sands, shales, and limestones, with marine fossils (*Myalina*, etc.), or with red beds in some sections (*Woodside shale*) 1000 to 1800 feet thick followed by limestones with shale beds up to 2000 feet in thickness (*Thaynes limestone*). In the lower part of this limestone is found the characteristic lower Triassic cephalopod, *Meekoceras* (Figs. 1586 *a*, *b*), one of the ceratite types, while other cephalopods occur in higher horizons (*Tirolites*, *Columbites*, Figs. 1586 *c–f*, etc.). In general, this series becomes more shaly and sandy as it is traced southward into Utah. Above the limestone follows a second clastic series

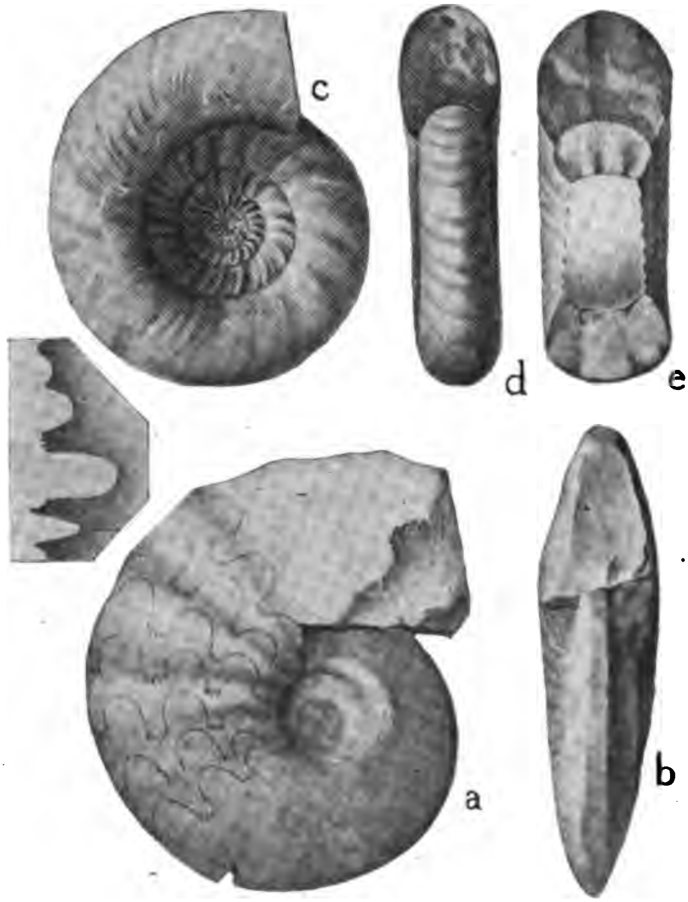


FIG. 1586. — Triassic cephalopods of western North America. (Cordilleran Piedmont basin; see Fig. 1582.) *a, b, Meekoceras gracilistriatum*, Lowest Triassic. *c–f, Columbites parisiensis*, Lower Triassic (above the *Meekoceras* beds). (I. F.)

(*Ankareh* shale, 670–1500 feet thick) with intercalated limestones, which merges southward into red or maroon-colored beds. This in turn is succeeded by a cross-bedded reddish or white sandstone (Nugget sandstone, 1900 feet thick) which may be in part of Jurassic age.

Canadian Extension and Alaska. — Shales and limestones with marine fossils are found farther north in the probable continuation of this basin, where they are often complicated by extensive volcanic beds. As the Palæocordilleran Mountain range probably passed beyond the present borders of the continent near the international line, the Triassic strata of the Pacific region of Canada belong in this belt and they are concordant with the underlying Palæozoic, having been deposited to the east of the deformed belt. These beds are exposed on Vancouver and Queen Charlotte Islands and again 150 miles east, on Thompson River in the Kamloops district of British Columbia. A northward continuation of this same series is found in Alaska where, though as yet little known, it rests disconformably upon the Palæozoics. Near Mt. St. Elias Triassic basalts have a thickness of 4000 feet, and are overlain by Upper Triassic limestones (*Chitistone* formation) of similar thickness, and these by dark shales 2500 feet thick. These beds were folded at the end of Triassic time, for the Jurassic beds lie unconformably upon them (Chitistone disturbance of Schuchert). Other Triassic beds, chiefly of marine origin, are widespread over Alaska as far as Cape Thompson on the northwest coast. Marine Triassic beds are also found on the islands of Arctic North America, northwest Greenland, and the Atlantic coast of eastern Greenland. (See map, Fig. 1569.) That the eastern border of the Triassic Piedmont basin lay to the east of the Rocky Mountain ranges in British Columbia is shown by the fact that, where the eastern range is cut by river channels, beds of Triassic age, often with marine fossils, are found.

Triassic of the Western (Cordilleran) Geosyncline

Western United States. — (See map, Fig. 1587.) The geosyncline which was developed in the oldland on the folding of the western Palæozoic strata (to form the Palæocordilleran Mountains and which lay to the west of these mountains, Fig. 1582) was apparently bounded on the west by a land mass of which the coastal ranges of California appear to be remnants. Whether this bounding land mass on the west was continuous or whether the Pacific had access to the geosyncline across it, cannot as yet be definitely determined. It is probable, however, that the geosyncline communicated with the Pacific on the north. The center of this western geosyncline seems to have been located where now lie the eastern ranges of the Sierra Nevada Mountains. In Inyo County, California, we find Lower Triassic marine strata with the characteristic ceratitic cephalopod, *Meekoceras gracilitatis*

FIG. 1587. — Palæogeographic map of North America, showing the distribution of land and sea (black) in Triassic time. (Original.)

(Fig. 1586 *a–b*), and other characteristic fossils belonging to the North Pacific fauna and closely related to forms found in the Himalayas, in southern Siberia, in Tibet, and in Spitzbergen. Upper Triassic strata are represented west of Lake Tahoe by black slates with interbedded limestones, apparently between 6000 and 10,000 feet thick.

In the West Humboldt range of Nevada the Triassic rocks formed in this geosyncline are again well exposed. They begin with arkosic sands of continental origin (*Koipato* group) representing, according to King, the erosion product of the Weber quartzite of Pennsylvanian age, which formed the crest of the old Palæocordilleran range on the east, and which was itself formed of the débris of the pre-Cambrian crystallines. The Koipato formation is over 6000 feet thick, and is followed conformably by the *Star Peak* group, over 10,000 feet thick and consisting of three great limestone zones with three interbedded quartzites, the lower of which is similar to the Koipato, while the upper are more silicious. The fossils of the lowest limestone indicate late Middle Triassic (Ladinic), while the highest beds represent the Noric horizon of Europe, the Rhætic being apparently absent.

In the Klamath Mountains of northern California we apparently approach the western border of this geosyncline, for there Lower Triassic beds are wanting, being overlapped by beds of Middle and Upper Triassic age. These beds comprise the following succession in descending order.

UPPER TRIASSIC

SHALES with *Pseudomonotis subcircularis* (Fig. 1588) (Noric), very thick.

HOSSELKUS LIMESTONE (partly Noric, mostly Karnic) . . . . . 400 feet

MIDDLE TRIASSIC

SHALES with *Protrachyceras homfrayi* (Ladinic) . . . . 100 feet

PITT FORMATION (Ladinic and Anisic?) . . . . 2000–3000 feet

Hiatus

PRE-TRIASSIC BASEMENT

The beds are all much disturbed by later folding and faulting. They have also suffered metamorphism, and have been subject to much erosion. In some sections (Redding region) the Pitt formation is preceded by flows and by tuffs of rhyolite (500 feet) and this by andesites (1000 feet) which rest upon Pennsylvanian beds.

Mexico and Central America. — The western geosyncline can be traced southward into Mexico and Central America. In the state of Sonora, Mexico, continental Upper Triassic (Keuper and Rhætic) beds with coal and plant remains occur. Farther south near Zacatecas City, marine Upper Triassic beds (Karnic), with characteristic fossils, and intimately associated with greenstones, rest unconformably upon the ancient schists and are themselves folded. Southwestward from this, in southern Mexico and Central America, only continental beds of Upper Triassic age are known. In

Nicaragua these carry cycad remains, and are cut by silver-bearing veins. They appear to have been deposited along the southwestern margin of a mountain range which extended through Mexico and Central America, apparently across the path of the northeasterly trade-winds which characterize this region to-day.

The Triassic of South America

Two thousand miles south from Nicaragua, in the Andes of Peru, Triassic beds are again found. The region which now constitutes the Andean chain was then a geosyncline, but whether this was a continuation of the western geosyncline of North America or not is undetermined. Both marine and non-marine deposits occur there, the former with the characteristic pelecypod *Pseudomonotis subcircularis* (Fig. 1588), found in the Upper Triassic of western North America (Noric), the latter with a Rhætic flora and sometimes with coal. Similar beds are also found in Argentine. Throughout most of this region the Upper Triassic beds are conformably succeeded by marine Lower Jurassic beds.

FIG. 1588. — *Pseudomonotis subcircularis*, left valve ×½. A characteristic pelecypod of the marine Upper Triassic of western North America, and Europe. (= *P. ochotica* of European authors.) (I. F.)

The Triassic of Europe

Lower Triassic. — The geography of Europe at the opening of Triassic time showed considerable modification from that of the preceding periods. A continuous land mass shut out the Atlantic on the west and northwest, this land extending from Scotland to Scandinavia on the one hand and to France, Spain, and North Africa on the other. The Armorican chain had become part of a broader land-mass which included most of France, but with the beginning of a north-south depression in the Rhone and Rhine Valley regions, which in Middle Triassic time became a pathway for the transgressing sea, the Variscian chain had become independent of the Armorican chain and was now continued southward in a mountainous peninsula through Corsica and Sardinia (Tyrrhenian peninsula). This independent system, the remnant of the Variscian chain, constituted the Vindelician chain of Mesozoic geography. Italy was apparently separated from Europe and formed a northward projecting peninsula from Africa. These features are shown in the accompanying palæogeographic map (Fig. 1589).

Three great basins of deposition existed at this time: the *North European*, occupying more or less of the area covered by the

FIG. 1589. — Palæogeographic map of Europe, showing the distribution of land and sea (black) and the areas of continental sedimentation in early Triassic time. V = the Vindelician chain with a southern extension into Sardinia and an eastern one north of the Tethys Sea. (Original.)

north European Permian basin; the *Balearic*, occupying the western Mediterranean of to-day between the Tyrrhenian peninsula and central Spain, and the *Main Mediterranean* basin, or *Tethys*,[1] which occupied the region of the modern Alps, part of the Balkan peninsula, and Greece, and thence extended eastward over the region occupied to-day by the Black Sea, the Caucasus Mountains, and the Caspian Sea, and on into southern Asia. This last basin was occupied by marine waters; during Lower Triassic time, the other two were dry basins which received only continental sedi-

[1] Named so by Suess, after Τηθύς, a sea-goddess, wife of Oceanus.

FIG. 1590. — New Red or Triassic Sandstone of Cheshire, England, showing eolian cross-bedding. (British Association, photo, from Lake and Rastall.)

ments, though in Middle Triassic time these, too, were flooded by the sea.

From the uplands on the west streams carried the product of disintegration of the rocks into the two western basins which, because of their mountain-enclosed character, were essentially deserts. These deposits are now represented by red and variegated sandstones, clays, and conglomerates, several thousand feet in thickness. They constitute the lower part of the *New Red Sandstone* of England (Fig. 1590), the *Vosgian sandstone* of northern France and the Vosges Mountains, and the *Bunter Sandstein* of the Black Forest and northern Germany in general. In the middle of this series the evidence of widespread desert conditions is most marked, many portions of the sandstone representing consolidated sand dunes. The modern Vosges and Black Forest regions were one of the centers of stream debouchure, for there the deposits are often very

FIG. 1591. — *Voltzia heterophylla*, a branch with long and short needles (leaves), one-half natural size, Lower Triassic (upper Buntsandstein). (After Steinmann.)

coarse, as they are along mountainous margins of modern deserts. The great mass of sediment came from the east and south from the Armorican land mass on the one hand and the Vindelician chain on the other. The Scandinavian region on the north appears to have been of low relief.

In the upper part of this sandstone series (*Röth* division) the remains of the coniferous trees (*Voltzia*, Fig. 1591) which grew

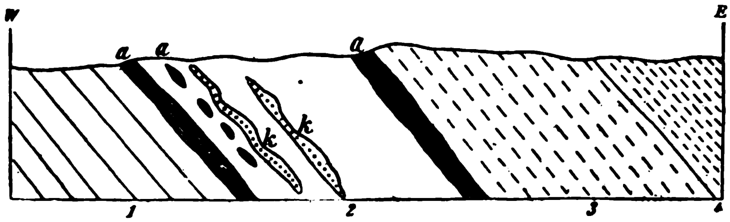


FIG. 1592. — Cross-section through Salzgitter, northwestern Germany. 1, Upper Buntsandstein (Röth) with *Myophoria costata;* 2, Rock salt with intercalations of anhydrite (*a*) and potash salt (*k*); 3, Red clays with *Myophoria costata;* 4, Muschelkalk. (After Kayser.)

upon the higher mountain slopes were buried in micaceous sandstones which were formed near the mountains, and which, farther in the basin, merge into marls, dolomites, and limestones, with a sparse marine fauna, which indicates that the sea had begun to transgress into this basin. As the climate was still semi-arid, gypsum and salt deposits, with some potash salts, were formed in marginal lagoons along the sea (Fig. 1592). Nevertheless, the climate was moister than during the earlier part of Triassic time. The great amphibians (*Chirotherium*) took advantage of this condition to wander far and wide

FIG. 1593. — Tracks (in relief) of *Chirotherium*, Buntsandstein, Hessberg, Germany. (From Haas' *Leitfossilien*.)

over these plains, and left their foot-prints in the sands and muds of the river flood-plains (Fig. 1593).

The Lower Triassic of the Balearic basin was deposited over southern France, the Pyrenees Mountains (a lowland at that time), eastern Spain, the Balearic Islands, and the west coast of Sardinia, together with the intervening region now buried beneath the waters of the Mediterranean but at that time the floor of a desert basin. In other words, the present mountains, islands, and sea bottoms of the region were replaced by a continuous level basin floor, nearly surrounded by mountains which have since disappeared. The source of the sediments, which are sands and clays, was chiefly in the uplands of France and Spain, and from these regions they spread outward, carried by intermittent streams and

FIG. 1594. — Diagrammatic section (ideal), showing the east-west relationship of the Triassic strata in northern Europe. In England the series comprises red sandstones throughout (New Red Sandstone), in Germany the threefold division into Buntsandstein, Muschelkalk, and Keuper is typically developed. (Original.)

in part probably by wind. Many of the beds are red, and the series generally begins with conglomerates which rest upon the eroded surfaces of various older formations. The thickness of the deposit in the center of this basin was about 500 meters. A remnant only of this is seen to-day on the Balearic Islands. Along the western margin of the Tyrrhenian peninsula, the sediments were chiefly of local origin. As was the case in the northern basin, the Lower Triassic of the Balearic basin shows in the upper portion the influence of the transgressing sea.

The main Mediterranean basin or Tethys, which at this time was bounded on the north by the Vindelician chain and on the west by the Tyrrhenian land tongue and the Italian peninsula (then a part of Africa), was occupied by the sea, and there the deposits are mainly of the marine type, though along the margin, especially in the lee of the western mountainous coast, heavy deposits accumulated, in part above the sea-level. It was there that the great salt deposits of the Alpine region (Salzburg, Hallstatt, Berchtesgarden, etc.) were formed in marginal lagoons of the sea, because the mountains acted as a barrier to the westerly winds and deprived them of their moisture, so that, when they descended on the east or leeward side, they had become drying winds. These salt deposits were exploited more than a thousand years before the beginning of the Christian era, and they are still an important source of salt in Europe. Many records of primitive salt workers

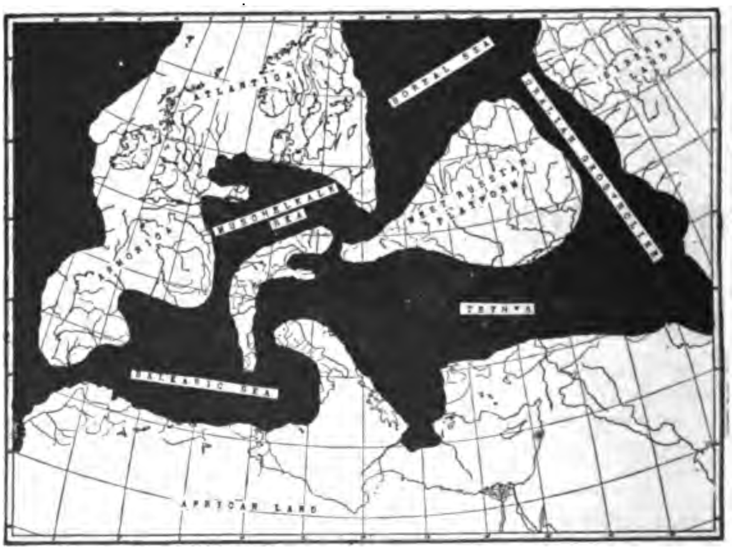


FIG. 1595. — Palæogeographic map of Europe, showing the distribution of land and sea (black) in Mid-Triassic time. (Original.)

have been preserved in some of the older mines, especially in the Hallstatt region.

Similar more or less continental beds of Lower Triassic age were formed along the eastern border of the Italian land mass, in the region of the present Balkan states, in parts of eastern Greece, and in Crete. More open marine deposits were formed farther east along the borders of the present Black Sea, and these waters extended eastward and became confluent with those which then covered northern India, the Himalaya region, southern Turkestan, etc.

The Middle Triassic. — This was a period of great transgression of the sea, which entered the basins where formerly continental

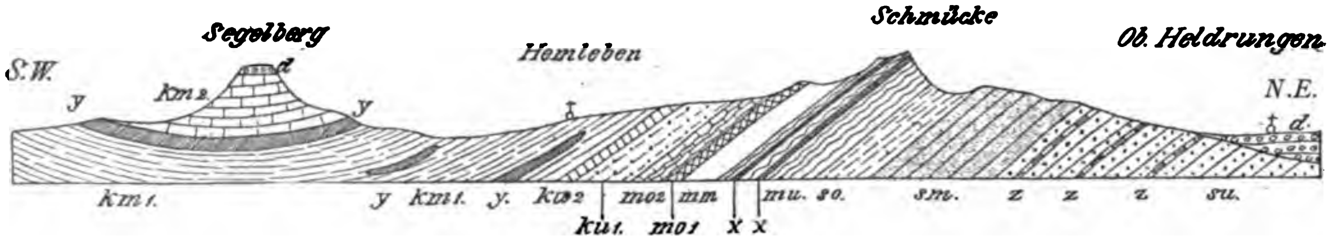


FIG. 1596. — Cross-section of the Triassic in the region of Heldrungen, in Thüringen. Buntsandstein (*su–so*); Muschelkalk (*mu–mo*$_2$); Keuper (*ku*$_1$–*km*$_2$), including beds of gypsum (*y*); *d* Diluvium. (After Kayser.)

FIG. 1597. — *Myophoria vulgaris*, a Middle Triassic (Muschelkalk) pelecypod.

FIG. 1598. — *Gervilleia socialis*, a Middle Triassic (Muschelkalk) pelecypod.

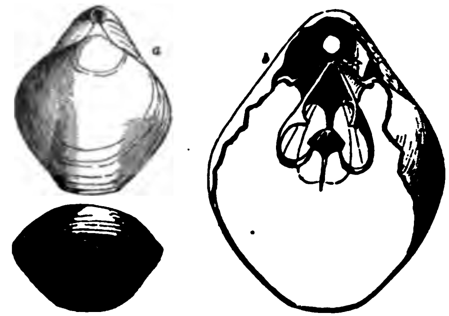


FIG. 1599. — *Terebratula* (*Cœnothyris*) *vulgaris*, two views, and enlarged view of arm support. Middle Triassic (Muschelkalk).

sedimentation prevailed, and so covered the continental beds with a marine limestone, the ***Muschelkalk***. Three distinct transgressive seas are recognizable: 1. The ***Boreal*** or Russian Sea, which penetrated into the north European Bunter basin (Fig. 1595), but did not reach England, where continental red beds continued to be deposited; 2. The ***Atlantic***, which entered across southern Spain, filling the Balearic basin, and became confluent with the northern basin through the Rhone-Rhine straits; and 3. The ***Mediterranean*** (Tethys) sea, which submerged a part of the Greco-Italian lands, and advanced to the foot of the Vindelician Mountains and the Tyrrhenian peninsula, becoming confluent around the southern part of this peninsula with the waters which filled the Balearic basin and, in the region of modern Silesia, establishing a connection with the northern basin, by a narrow strait. These connections are indicated by the intermigration of distinct types of organisms characteristic of each of the three water bodies, and they are shown on the accompanying palæogeographic map of Mid-Triassic time (Fig. 1595).

FIG. 1600.—*Encrinus liliiformis*, stem joints, and basal view of calyx (reduced). Middle Triassic (Muschelkalk).

The Muschelkalk of the North German basin shows a threefold development, marine limestone at the bottom and top, and gypsum and salt beds in the middle (Fig. 1596). This indicates that after the first advance of the sea a retreat set in with evaporation of the entrapped sea water, and later a second advance of the sea covered these precipitates. The lower Muschelkalk contains mainly the remains of pelecypods (*Myophoria*, Fig. 1597; *Gervilleia*, etc., Fig. 1598), certain forms of ceratitic cephalopods (*Hungarites*, etc.), and brachiopods (*Terebratula*, Fig. 1599; *Spiriferina*, etc.). The upper Muschelkalk had a very distinct fauna in which two striking types, the crinoid *Encrinus liliiformis* (Fig. 1600) and the cephalopod *Ceratites* (Fig. 1601) form the dominant element. The latter appears to be an emigrant from the Atlantic through the Balearic basin, for the deposits along the western border of that basin carry this fossil, while the eastern part contains only

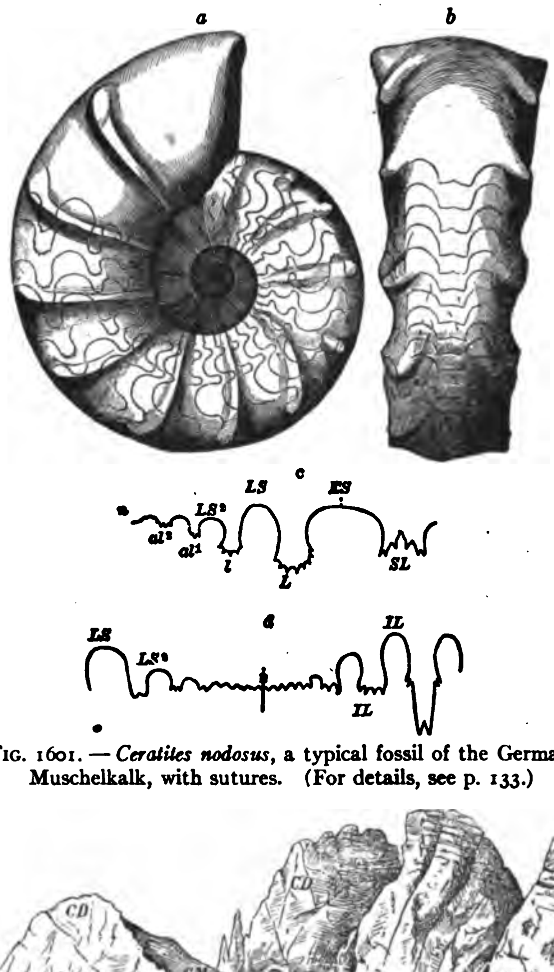


FIG. 1601. — *Ceratites nodosus*, a typical fossil of the German Muschelkalk, with sutures. (For details, see p. 133.)

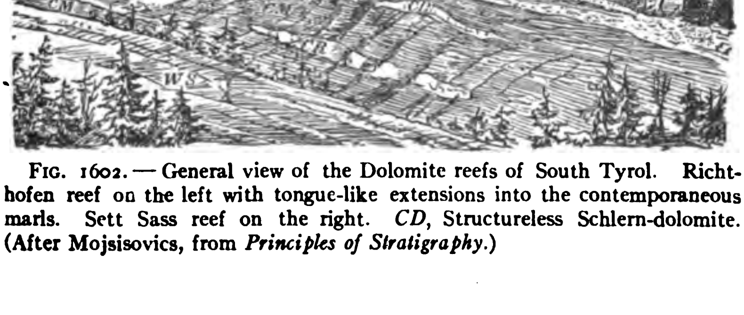


FIG. 1602. — General view of the Dolomite reefs of South Tyrol. Richthofen reef on the left with tongue-like extensions into the contemporaneous marls. Sett Sass reef on the right. *CD*, Structureless Schlern-dolomite. (After Mojsisovics, from *Principles of Stratigraphy*.)

fossils of the Mediterranean (Alpine) basin. In the latter great limestones and dolomites, often of reef-like character (Figs. 1602,

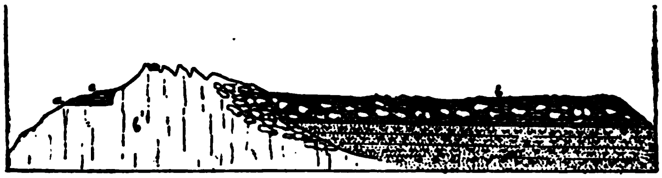


FIG. 1603. — Section of Schlern massif or Triassic dolomite reef of South Tyrol, showing the relationship of the reef-rock and bedded formations. (After Mojsisovics, from *Principles of Stratigraphy*.)

1603) and chiefly composed of calcareous algæ (*Diplopora*, Fig. 1604), were formed. These calcareous beds, together with others formed during the Upper Triassic, constitute to-day an important part of the Alps, where, after uplift and pronounced disturbance followed by prolonged erosion, much still remains, including the great reef masses of the Dolomites in the Tyrol (Fig. 4, p. 9, Pt. I), where continuous deposition of lime produced masses over 3000 feet thick. Some of these beds contain numerous ceratites (Fig. 1605) and other mollusks, but of species restricted to this basin and its eastward continuation into the Triassic basins of Asia, except in so far as this Alpine or Mediterranean fauna, as it is called, migrated part way into the other basins. The typical Muschelkalk ceratite (*Ceratites nodosus*, Fig. 1601) is, however, absent from the Alpine Triassic deposits. Some of these Mediterranean species are also characteristic of the west American marine Triassic, among them the pelecypod *Daonella lommelli* (Fig. 1606 *a*).

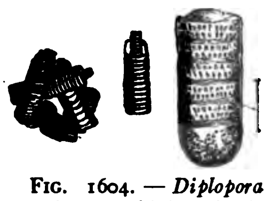


FIG. 1604. — *Diplopora annulata*, a Middle Triassic (Ladinian) alga of the Alps. (After Kayser.) (See also Fig. 5, p. 10, Pt. I.)

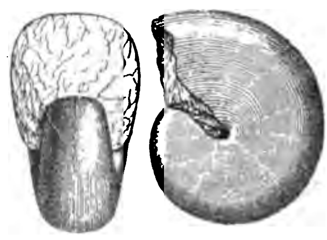


FIG. 1605. — A characteristic ceratite of the Triassic limestone of the Alpine region. Reduced one-fourth. (*Cladiscites tornatus*.)

Upper Triassic. — This epoch witnessed a retreat of the sea from the northern and western basins and a resumption of continental sedimentation. At first shales were formed in relict water-bodies in the central part of the basin, where pelecypods

(*Myophoria goldfussi*, Fig. 1606 *b*, etc.) related to those of the middle period still lingered. These deposits passed laterally into river-laid plant-bearing sediments which occasionally advanced over the relict seas and killed their faunas. Then numerous fresh-water ponds came into existence, in which lived the little bivalve crustacean *Estheria* (Fig. 1607), and where vegetation grew in

FIG. 1606 *a*. — ***Daonella lommelli***, a Middle Triassic (Ladinian) pelecypod of the Alps and western North America. (After Kayser.)

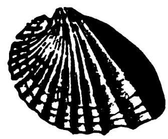


FIG. 1606 *b*. — ***Myophoria goldfussi***, an Upper Triassic (Keuper) pelecypod. (After Kayser.)

sufficient quantity to give the deposits a highly bituminous character. River-fish and land-reptiles, too, were embedded in these deposits. As the climate became more arid, gypsum deposits were formed over many parts of the northern basin, probably because of partial evaporation following repeated inundations of the sea. In some sections (Lorraine) salt deposits also were formed in

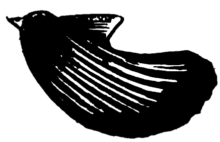


FIG. 1606 *c*. — ***Avicula contorta***, an Upper Triassic (Rhætic) pelecypod. (After Kayser.)

FIG. 1607. — Slab of rock with ***Estheria minuta***, Upper Triassic (Keuper) crustaceans of America and Europe. (After Kayser.)

marginal lagoons of the retreating sea. By this time the connections with the Balearic and Mediterranean basins had ceased to exist, the conditions thus returning to those of Lower Triassic time. The higher Keuper beds are sandstones, with plant and reptilian remains, and thick beds of varicolored clays, with calcareous concretions and with remains of large dinosaurs.

Finally, the series is closed by the Rhætic sands, which mark a readvance of the sea, since many of the beds contain a sparse marine fauna (*Avicula contorta*, Fig. 1606 *c*, etc.). Remains of

Fig. 1608. — Typical scenery formed by the Wetterstein limestone, Middle Triassic (Ladinic) in the northern Alps. The elevation of the hut is 1605 meters.

fresh-water and land organisms also occur in many sections, showing that the marine conditions were not fully reëstablished.

In England these Upper Triassic beds are sandstones and marls, and carry important salt deposits which appear not to be of marine but of desert origin, without basal gypsum beds (p. 234, Pt. I). The fossils of these beds are mainly vertebrates, the fresh-water crustacean, *Estheria*, and some fresh-water Mollusca. The re-

Fig. 1609. — Typical mountain slope of Upper Triassic (Noric) limestone, "Haupt dolomite," northern Alps. (Gufel on the Bockkarkopf.)

lationships of the English and North German Triassic beds are shown in a preceding diagram (Fig. 1594, p. 629).

The Upper Triassic beds of the Balearic basin are essentially similar to those of the northern basin, except that more salt was formed along the sea margin, especially in Spain. In the Mediterranean basin marine conditions continued with the formation of extensive limestones, some of which represent very shallow water deposits. Many of the great limestone deposits of the Balkan peninsula and of Greece were formed at this period. The characteristic appearance of the Triassic limestones of the Northern Alps (Mediterranean basin type) is shown in Figures 1608–1610.

The Triassic of Other Continents

In Asia the marine Upper Triassic is best developed in the Himalayas while other regions were the sites of continental plant-bearing deposits which often rest directly upon pre-Triassic rocks.

Fig. 1610. — Summit of the Dachstein in the northern limestone Alps, Austria. (After Haug.)

In South Africa the upper part of the great continental Karoo formation is of Triassic age, the lower part being Permian and resting upon the Dwyka glacial conglomerates.

Characteristic Life of the Triassic

Marine Organisms. — Lime-secreting **Algæ** were abundant in the Triassic sea, especially in the Mediterranean basin, where great reef-like masses, such as those of the Dolomites, were largely formed by a few

FIG. 1611 *a.* — *Koninckina leonhardi*, a Middle Triassic (Ladinian) brachiopod of the Alps, showing the small ventral valve, the large pedicle valve, and the internal spiral arm supports. (After Kayser.)

FIG. 1611 *b.* — *Lima striata*, an Upper Triassic (Muschelkalk) pelecypod. (After Kayser.)

species (*Diplopora*, etc., Fig. 1604). It is now thought that the magnesian content of these rocks is largely due to algal secretion. **Corals** are not uncommon in some of the Triassic limestones, especially of the Alpine or Mediterranean region. The Palæozoic types of Tetraseptata have become

FIG. 1612. — A Triassic *Nautilus* (*Proclydonautilus triadicus*, $\times\frac{1}{3}$) from the Upper Triassic of California and Europe. The suture in this form has pronounced lateral and ventral lobes suggestive of goniatites but simpler. The other characters are nautilian. One-third natural size. (I. F.)

almost extinct — though a few forms linger on. The Triassic corals are chiefly Hexaseptata, a division most typically represented in modern reefs. Common genera are *Thecosmilia* (Fig. 1646), *Montlivaultia* (Fig. 1647), *Isastræa* (Fig. 1645), *Thamnastræa* (Fig. 1644), etc., all genera which are also represented in later Mesozoic beds. **Brachiopods** are much restricted in number of genera, the chief ones being the punctate *Spiriferina*, *Terebratula* (Fig. 1599), and *Rhynchonella*. A remarkable form restricted to the Triassic is *Koninckina* (Fig. 1611 *a*), which has the appearance of a

FIG. 1613. — *Macroptæniopteris magnifolia*, a characteristic fern of the Newark (Upper Triassic) strata of Virginia and North Carolina. Restored. (After Russell, U. S. G. S.)

small *Productus*. Among **Pelecypods** the genera *Myalina*, *Myophoria* (Figs. 1597, 1606 *b*), *Gervilleia* (Fig. 1598), *Cardita*, together with *Lima* (Fig. 1611 *b*), *Monotis*, *Pseudomonotis* (Fig. 1588), *Halobia*, *Daonella* (Fig. 1606 *a*), and others are characteristic. **Gastropods**, too, abound especially in the Alpine Trias, there being still some left-over Palæozoic types (*Bellerophon*, *Murchisonia*, *Loxonema*) while modern genera (*Cerithium*, *Emarginula*, etc.) also have appeared. The **Cephalopods** are, however, by far the most important index-fossils, being represented by a vast number of ammonoid genera and species, most of them with ceratitic sutures. *Ceratites* (Fig. 1601) itself is typically represented in the Muschelkalk and its equivalent beds in Spain, etc., but is not characteristic of the Alpine or American Trias, where, however, other ceratitic genera abound. In the basal portion of the West American and Asiatic Trias, the ceratite genus *Meekoceras* (Fig. 1586) is a characteristic index fossil. The *Nautilus* type is also well represented, but chiefly by specialized genera with strongly lobed sutures (Fig. 1612).

The **Crinoids** are represented by several species of *Encrinus*, of which *E. liliiformis* (Fig. 1600) is the most characteristic in the upper Muschelkalk. Of **Echinoids**, the genus *Cidaris* is the most abundant in the Alpine Triassic beds.

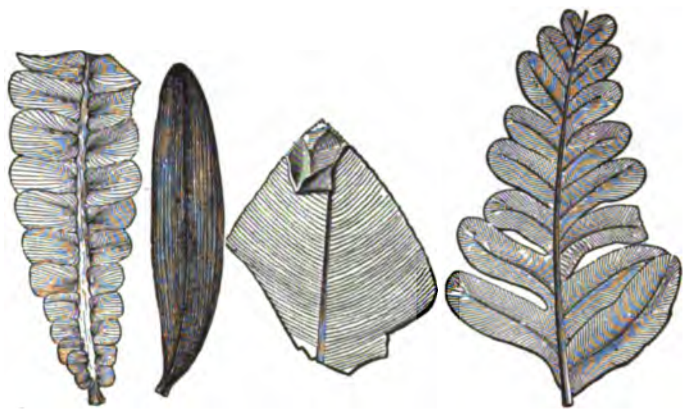
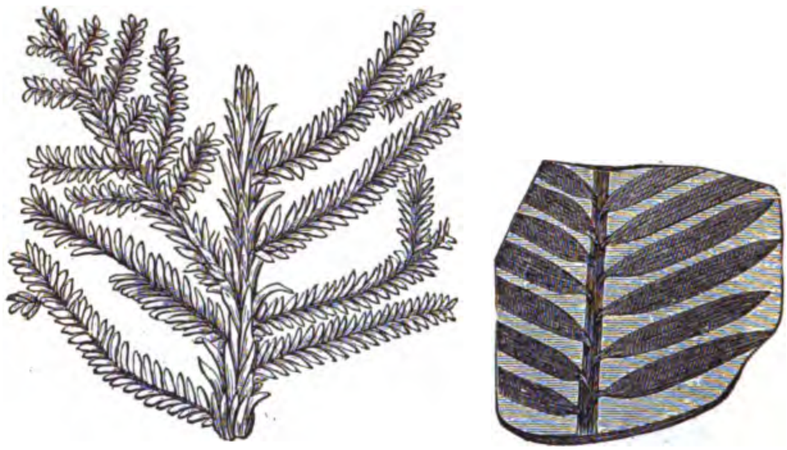


FIG. 1614. — Upper Triassic (Rhætic) plants. *a*, *Otozamites macombii*; *b*, *Podozamites crassifolia*; *c*, *Tæniopteris elegans*; *d*, *Alethopteris whitneyi*. *a*, *b*, cycads; *c*, *d*, ferns. (After Newberry.)

Fresh-water Faunas. — These consist mainly of fish, and of the fresh-water phyllopod-crustacean, *Estheria* (Fig. 1607), which occurs in countless numbers in some shales. Fresh-water mollusks (Unios), however, also occur. The river-fish belong mainly to the ganoids, the two most characteristic American genera being *Catopterus* (Fig. 1570), and *Ischypterus* (Fig. 1571). Crocodiles were also very characteristic of the Triassic rivers, their bones (*Mystriosuchus*, *Belodon*, Fig. 1783, etc.) abounding in the continental Trias of the western United States.

Land Life. — This included insects whose trails are most frequently found, amphibia, and dinosaur reptiles, the foot-prints of which are most characteristic of these continental deposits. These animals will be referred to again in a later chapter. The land flora was rather meager: not more than 400 species are as yet known (150 American) and these consist mainly of ferns, cycads, and conifers. The most characteristic were the giant fern, *Macroplæniopteris* (Fig. 1613) in the American Upper Trias and the conifer *Voltzia* (Fig. 1591) for the European continental Lower Trias. The flora of the Rhætic beds has already a Jurassic stamp with ferns, cycads (*Wielandiella*, *Williamsonia*, *Otozamites*, etc.), and conifers. Figs. 1614–1616.



a *b*

Fig. 1615. — Fossil plants of the North Carolina and Richmond, Va., coal-basins (Triassic). *a*, ***Walchia diffusus***, a conifer; *b*, ***Podozamites emmonsi***, a cycad. (After Emmons.)

a *b* *c* *d*

Fig. 1616. — Plants. *a*, branch of conifer (***Brachyphyllum***); *b*, ***Zamites occidentalis***, a cycad; *c*, conifer, branch and fruit; *d*, branch of conifer. (After Newberry.)

CHAPTER XLII

THE JURASSIC SYSTEM

THE formations grouped together in this system are among the most widespread and interesting in Europe, but they are sparingly developed in North America, where they are chiefly represented by continental deposits except in the Cordilleran and Mexican regions. The study of these formations was first undertaken in England by William Smith early in the last century, when he established the main subdivisions, the Lias and the several Oölites. The fine development of the rocks, with the fossils of the English Oölites, in the Swiss Jura suggested the name *Jurassic* for the system, a name first applied by Brongniart and von Humboldt. The wonderfully preserved fossils of these formations are found in many parts of France, and on the basis of their vertical distribution the French palæontologist Alcide d'Orbigny was able to establish a tenfold division, which has proved more or less applicable to other countries as well. The names of these divisions are largely those given to the English beds by William Smith and his immediate successors. In Germany, on the other hand, the lithological as well as faunal characters suggested a threefold subdivision, and this was applied by Leopold von Buch, the pupil of Werner, who also introduced the terms Black, Brown, and White Jura, from the prevailing colors of the lower, middle, and upper divisions, respectively. These three divisions have also come to be known by the names of *Lias* (the English term for the lower division), *Dogger* (from the presence of large concretions or dogger-heads), and *Malm*, terms still in very general use.

The finest series of exposures of these strata are seen in the Swabian Alp of Germany (Fig. 1617). This is in reality a great cuesta, formed by the resistant Upper Jurassic limestones (Malm) and the weaker Middle and Lower Jurassic sands and clays beneath.

The front of this cuesta rises nearly a thousand feet above the lowlands on the north, and the many sections which were cut into it by the obsequent and other streams, and by the railroads

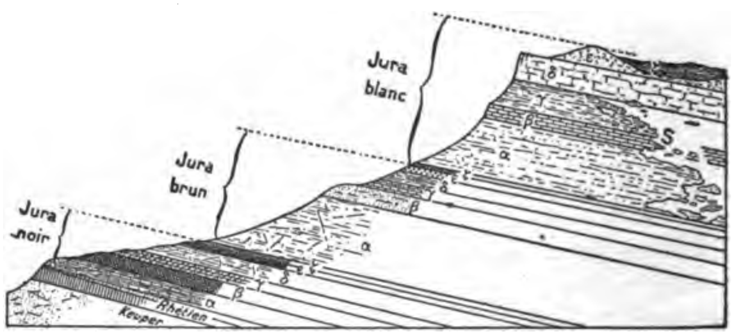


FIG. 1617. — Section of the Swabian Alp in southern Germany, a typical locality in which the subdivision of the Jurassic rocks was carried into great detail by Quenstedt and others. (After Haug.)

and highways which descend over it, as well as the quarries, furnished excellent opportunities for the study of these rocks and the collections of their fossils. To this task Friedrich August Quenstedt (portrait, Fig. 1618), for many years Professor in Tübingen University, devoted himself with extraordinary vigor, and he described and pictured these fossils in a series of great monographs which have become the standard reference works for later investigators. Quenstedt's achievements in Jurassic stratigraphy and palæontology were fittingly recognized by the erection of a monument to his memory on the heights of the Swabian Alp from whose stony tablets he had deciphered so many chapters of Jurassic history. Quenstedt's pupils and their pupils after them continued this work, not only in Germany but in many and often distant regions of the world, until to-day the Jurassic is perhaps better known than any other similar system of formations.

FIG. 1618. — FRIEDRICH AUGUST QUENSTEDT.

Subdivisions of the Jurassic

The Jurassic system readily admits of a threefold division as follows:

3. Upper or White Jura or Malm.
2. Middle or Brown Jura or Dogger.
1. Lower or Black Jura or Lias.

The further subdivisions based upon the French and English development are very generally used, the principal ones being as follows:

Upper Jurassic or Malm		Purbeckian
		Portlandian
		Kimmeridgian
		Lusitanian or Corallian
Middle Jurassic or Dogger		Oxfordian [1]
		Callovian
		Bathonian
		Bajocian
Lower Jurassic or Lias	Upper	Aalenian
		Toarcian
	Middle	Domerian
		Pliensbachian
	Lower	Lotharingian
		Sinemurian
		Hettangian

The Jurassic of North America

Marine Jurassic beds are found in North America in the Gulf region (Texas, Cuba, Mexico), in the Cordilleran geosyncline, and to a certain extent in that of the Cordilleran Piedmont basin east of the ancient Palæocordilleran range of folded Palæozoic rocks. Continental deposits, of late Jurassic or Comanchean age, are also found in the Atlantic coastal region, but these will be discussed in connection with the Comanchean sediments where they are more generally placed.

Marine Jurassic of the Gulf Region

In Jurassic time the old barrier formed by the land mass of Appalachia had become broken through so that the waters of the Atlantic with the fauna of the European Jurassic could enter into

[1] Used here in the restricted sense, the Old Lower Oxford, *i.e.* the Oxford Clay. The Lusitanian or Corallian is Upper Oxford.

the Gulf of Mexico region. Deposits of Jurassic age are found in western Cuba and in several places in Mexico, and they extend northward into western Texas. Over most of the regions only Upper Jurassic beds are known, this being especially the case in Mexico and Texas, but in Cuba late Middle Jurassic beds

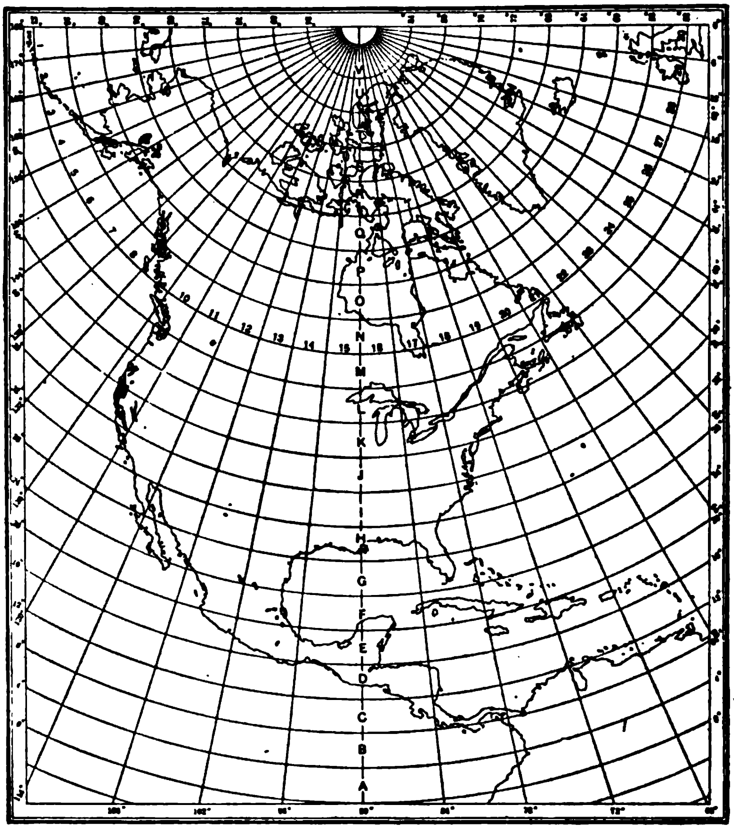


FIG. 1619. — Map showing the outcrops of the Jurassic rocks in North America. (After Bailey Willis.)

(Oxfordian) and perhaps older beds are also found, while in Puebla and Vera Cruz, black and yellow clay-slates with Liassic fossils occur, followed by Upper Jurassic beds with apparently a hiatus between them.

The overlaps of the formations in Mexico are from the southeast, westward and northward, indicating a transgression of the arm of the Atlantic Ocean, and this apparently never became confluent with the waters of the western geosyncline (map, Fig.

Fig. 1620. — Palæogeographic map of North America in Neo-Jurassic time, showing the distribution of land and sea (black). (Original.)

1620). Moreover, the faunas of the Mexican and Cuban deposits have a west European character, while those of the western geosyncline are mostly Asiatic types.

Along the margin of this eastern sea, in the lee of the mountains which bounded it on the west, gypsum and probably salt were deposited, especially in the Texas region. It is not improbable that the salt from which the salt domes of the Gulf region were formed in Tertiary time was originally deposited by this Jurassic sea.

The Jurassic of the Cordilleran Piedmont Basin

The Triassic red beds of northeastern Arizona, northwest New Mexico, Utah, and Colorado are generally followed by white sandstones which often show the characteristic eolian cross-bedding in a most wonderful manner and are apparently consolidated

FIG. 1621. — Detailed view of cross-bedding of eolian type in White Cliff Sandstone (Jurassic), Colorado. (H. S. Gale, photo; from U. S. Geological Survey.)

desert sands (pp. 453–457, Pt. I, also Figs. 1621–1622 *a*). They are of such striking character that their outcrops in the Grand Cañon region form the *White Cliff*, that name also being applied to the sandstone, whereas farther north in Colorado, etc., it is known as the *La Plata sandstone*. Its thickness in the southern region ranges up to 2000 feet, but northward it becomes thinner and is only 500 feet thick in southwestern Colorado. The ancient desert area over which these sands were distributed was nearly equal in extent to the sandy portion of the modern Libyan desert in northeast Africa, if not larger, and had probably very much the character of that desert. Where this sandstone lies upon the Triassic red beds (Dolores or Vermilion Cliff beds), it is generally separated from them by an erosion interval, and in many cases a considerable amount of the older formations had been removed before these sands were deposited. It is not at all improbable that a large portion of the sands was derived from the destruction of these older beds, just

FIG. 1622. — Cross-bedded sandstone, Little Meadow Gulch, Utah. (Gardner Collection of Photographs, Harvard University. Courtesy Geological Department.)

as the sands of the Libyan desert are derived from the destruction of the older Nubian sandstone, a part of which is still preserved on the borders of the Libyan desert and other districts of Egypt.

Into this west American desert of Jurassic time the sea penetrated from the northwest, extending as far south as the high plateau region of Utah, where the eolian sandstone is succeeded by about 250 feet of fossiliferous shales with limestone beds and here and there beds of gypsum which were formed in marginal lagoons. Northward the marine series is thicker, for these areas were the earlier ones to suffer invasion. Thus in southwestern

FIG. 1622 *a*. — Navajo Church, an erosion monument cut from white cross-bedded Jurassic sandstone (Zuñi sandstone). Northwestern New Mexico (U. S. G. S.).

Wyoming a series of dark calcareous shales and shaly limestones 3500 to 3800 feet thick, with some sandstone beds, represents the deposits of this marine invasion (*Twin-Creek* formation), but is again overlain by a thick series of red beds (*Beckwith* formation), in part of Upper Jurassic and in part of Comanchean age. These marine Jurassic beds are recognized on both sides of the Rocky Mountain Front Range, and they extend as far east as the Black Hills uplift or dome. Both this and the Front Range are elevations of more recent date. In many sections of this region the Jurassic and older as well as younger (Cretaceous) strata are strongly folded and much disturbed by thrust faults, while erosion has removed considerable portions of them over wide areas.

FIG. 1623. — *Camptonectes bellistriatus*, a right valve. A characteristic pecten of the Upper Jurassic of the Colorado geosyncline. Reduced one-half. (I. F.)

As exposed in the Front Range region of Colorado, the marine Jurassic series consists of clays and sands with marine fossils, and varies from 100 to 150 feet or more in thickness (*Sundance* formation). In the Black Hills it has a similar character, while in the Big Horn

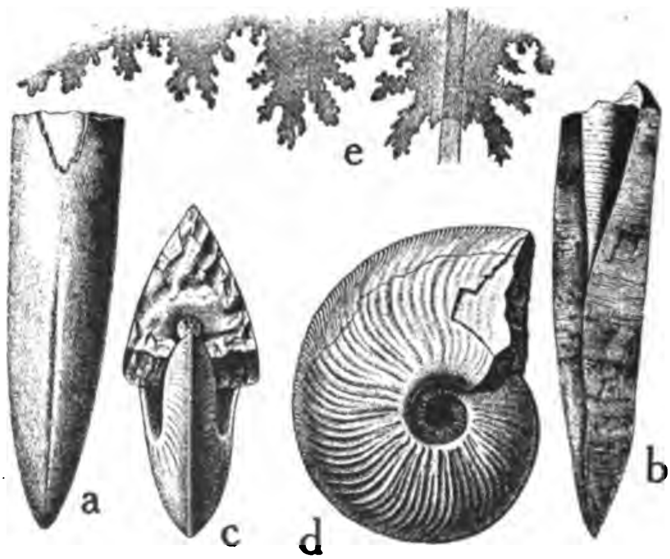


FIG. 1624. — Jurassic cephalopods. *a*, *b*, *Belemnites densus*, Upper Jurassic of Colorado geosyncline; (*a*, external view of guard; *b*, longitudinal section of guard showing the short, septate phragmocone in place (×⅘)); *c–e*, *Cardioceras cordiformis*, side and front views (×⅘), and suture enlarged, Upper Jurassic of the Black Hills (Colorado geosyncline).

Mountains it ranges up to 300 feet in thickness and has some limestone members. Its most characteristic fossils are Belemnites (*B. densus*, Figs. 1624 *a*, *b*), pelecypods (*Gryphæa calceola*, *G. nebraskensis*, *Camptonectes bellistriatus*, Fig. 1623), and many species of *Trigonia*, five-sided crinoid stems (*Pentacrinus astericus*) and ichthyosaurs. In British Columbia the marine Jurassic is represented by 1600 feet of black shales with some limestones and sandstones containing characteristic fossils (*Fernie shales*). Throughout the greater part of the basin the marine Triassic strata are succeeded by the *Morrison* continental formation, mostly of Comanchean age, derived from the erosion of the Palæocordilleran Mountains and spread from the southwest northward and eastward. This formation contains the remains of dinosaurs and of plants and fresh-water invertebrates. The original area over which this series of sediments was spread as a continuous sheet was probably several hundred thousand square miles, but from many thousands of square miles it has been eroded, while large areas of it are covered by younger strata.

Jurassic Deposits of the Cordilleran Geosyncline

In the western or Cordilleran geosyncline we find the only relatively complete marine series of Jurassic beds which is recognized in North America. The Lias is represented in the Humboldt range of western Nevada, where it consists of 1500 to 2000 feet of limestones resting upon the Star Peak group (Triassic) and followed by about 4000 feet of shales of later Jurassic age. In northern California (Taylorville region), the following succession of Jurassic strata is recognized in descending order.

MALM	Foreman formation (Kimmeridgian (?) to Purbeckian)	
	Hinchman tuff (Corallian)	50 to 500 feet
DOGGER	*Hiatus*	
	Bicknell sandstone (Callovian)	500 to 1000 feet
	Hiatus	
	Mormon sandstone (Upper Bajocian)	95 to 550 feet
	Thompson limestone (Lower Bajocian)	
LIAS	Hardgrave sandstone	850 feet
	Trail formation	2900 feet
	Disconformity	

TRIASSIC. — Schwearinger slates.

The Trail formation of Liassic age is non-marine and contains remains of plants and *Estheria*. It consists mostly of shales, with some sandstones and conglomerates with large pebbles, often of volcanic material and beds of tuff. The *Hardgrave sandstone* is fossiliferous, and marks the transgression of the sea over this area in upper Liassic time. The succeeding *Thompson limestone* and *Mormon sandstone* represent the Bajocian of Europe, while the *Bicknell sandstone* is of Callovian age. The Bathonian seems to be unrepresented, as is also the Oxfordian, probably because there are breaks in the series at these horizons. Of the Upper Jurassic only the lowest division (*Hinchman tuff*, Corallian) is marine, the remainder of the series being, in part at least, a non-marine formation (*Foreman* beds) with plants and some intercalated beds with marine invertebrates. These northern California Jurassic formations were apparently deposited near the western border of the geosyncline, and this accounts for their prevailing terrigenous character and the breaks in the series. In this section the beds are often red, whereas on the eastern side of the trough they are gray. This suggests the prevalence of westerly winds at the time of deposition. In the Sierra Nevada range the Jurassic beds are much metamorphosed slates, penetrated by gold-bearing veins (*Mariposa* formation). Their age is Upper Jurassic. Similar Jurassic beds are found in northwestern Washington and farther north.

During early and Mid-Jurassic time the organisms of this sea were apparently of southern or warm-water origin, but in later Jurassic time the northern or boreal fauna entered this region, and a small assemblage of organisms, in which the pelecypod *Aucella* (Fig. 1651) was well represented, appeared in these waters.

The greatest development of Jurassic strata is, however, found in Alaska, where they rest unconformably upon the folded and eroded Triassic. The series begins with tuffs and sandstones 1000 feet thick, followed and overlapped by 1500 to 2500 feet of shales, sandstones, and conglomerates of Middle Jurassic age (*Enochkin* formation), and this by conglomerates, arkose sandstones, and shales with interstratified andesite flows, the whole being about 5000 feet thick. Faunally this series corresponds to the California formations. In northwestern Alaska the Jurassic is represented by a vast thickness of continental beds with plant remains.

The Andean Geosyncline of South America

Marine Jurassic beds are found in a number of localities in the Andes Mountains, and it has been shown that this region was a great geosyncline, the eastern boundary of which was some distance east of the 70th meridian. Its western boundary was formed by a land mass now largely buried beneath the Pacific, but the eastern border was in part, at least, east of the present western coast of South America. The fossils of these Jurassic beds indicate that the geosyncline was in communication with the Pacific, for types also known in India are found there. There may also have been a temporary connection with the Gulf of Mexico embayment.

The Jurassic of Europe

Lower Jurassic or Lias. — When we compare the map of Europe at the opening of the Jurassic with that of the greatest sea-extension in Mid-Triassic time, we find an essential agreement

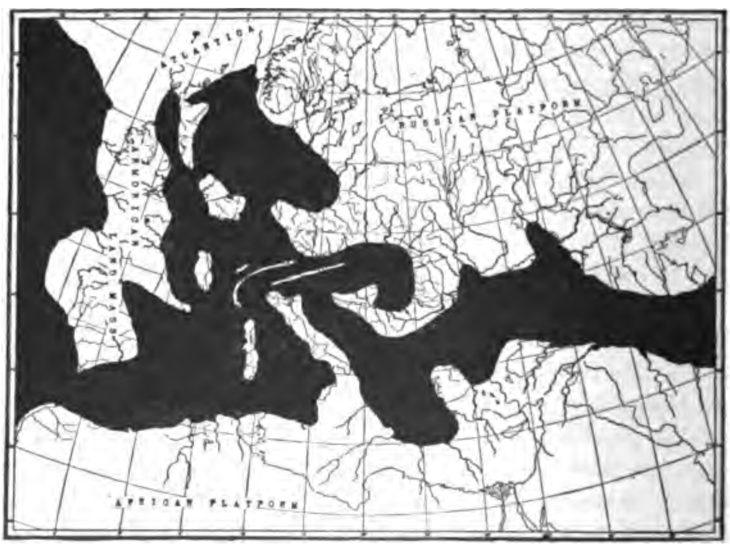


Fig. 1625. — Palæogeographic map of Europe in early Jurassic (Liassic) time, showing the distribution of land and sea (black). (Original.)

in the general character and extent of sea and land, though with some marked changes brought about chiefly by the erosive activity in late Triassic time. One of these was the almost complete disappearance of the Vindelician Mountain chain, except for a series of long, low island-like ridges. Another important change seems to have been the disappearance of the northwest Russian sea, land taking its place (map, Fig. 1625).

In the main or eastern Mediterranean basin (Tethys), especially in the region of the modern Alps, where the Triassic was represented by great limestone deposits, such sedimentation continued, so that Liassic limestones here follow upon those of Triassic age. The sea, which had been transgressing in Rhætic time, continued to advance, submerging a part of the Armorican land mass, so that much of France was beneath the same sea which covered a great part of England and transgressed far to the north on each side of Scotland, leaving that country in the form of a southward projecting peninsula from the North Atlantic lands. This northern sea also covered part of north Germany, extending for some distance east of Berlin. The Balearic basin was completely filled by the sea, which was in communication with the Atlantic across southern Spain and with the eastern Mediterranean through the Alpine region, and, finally, with the northern sea through the Rhone-Rhine depression. Thus in both the northern and the Balearic basins, marine Liassic (and often the Rhætic beneath it) rests upon continental Keuper, whereas in the main Mediterranean basin (Tethys), marine Liassic follows upon marine Triassic beds.

We must picture to ourselves the Mediterranean Sea as transgressing northward over the lowlands of North Europe which were covered by Keuper muds, while the Atlantic in a similar manner transgressed over the southwestern basin. Thus while the sea was clear in the Alpine region and in France and elsewhere, the extension over north Europe was, for the most part, a shallow muddy basin in which comparatively few organisms could live. The mud may have been in part the accumulated sediment of Triassic time; in part it was newly supplied by the rivers. But on account of the extensive decay of organic matter, so characteristic of stagnant water bodies, the mud-rocks which were formed are in most cases dark or even black and highly bituminous.

Alternating with these bituminous beds are heavy bedded sandstones and some thin limestones, and these usually contain many ammonite shells, some of them reaching the extreme diameter of five or six feet. In the bituminous shales the wonderfully preserved remains of marine saurians (*Ichthyosaurus*, Fig.

1629, etc.) are found, two famous localities for these fossils being Lyme Regis in southern England and Holzmaden near Stuttgart in Württemberg. By the most careful and painstaking removal

FIG. 1626. — Quarry in the Posidonia slates of the upper Lias, at Holzmaden in Württemberg, Bavaria. The quarry is only 7 meters in depth, the slabs quarried are 20 cm. in thickness and represent the bedding of the series. The left wall of the quarry is a natural joint, the right side is made of discarded fragments. At the point marked + on the rear wall the specimen represented in the succeeding figures was found. In 1911, more than 25 such quarries were in operation in this region. These furnish during the year about 100 specimens of saurians of which on the average only 10 are sufficiently perfect to warrant preparation. (Photo by courtesy of Bernard Hauff Holzmaden-Teck.)

of the rock matrix, these reptile remains are uncovered and the specimens thus obtained have enriched the museums of the world (Figs. 1626–1630).

It has been held that these animals died in stagnant seas of the Black Sea type, and that their bodies settled to the bottom and were buried by the fine mud accumulating there. It may

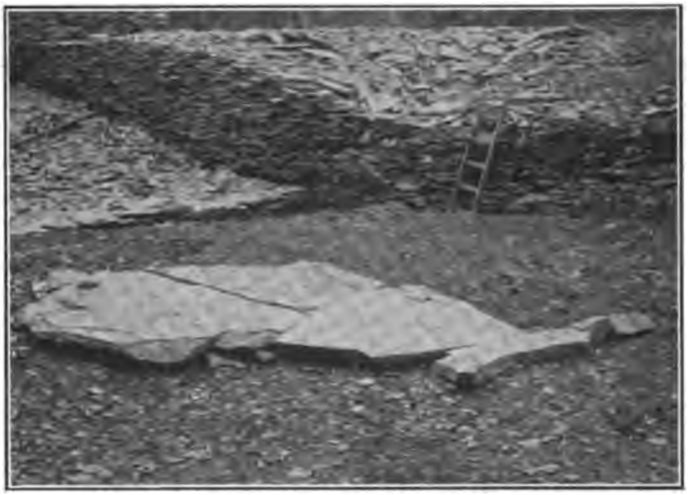


FIG. 1627. — Slab of slate containing an *Ichthyosaurus* 3.5 meters long; immediately after removal from the quarry. The tail end, 0.6 m. long, is still in the quarry at the point marked + (Fig. 1626). (Photo by courtesy of Bernard Hauff, Holzmaden-Teck.)

be doubted, however, if any part of the Liassic sea was a deep basin like that of the Black Sea. Indeed, the heavy sandstones testify to the contrary. It seems more likely that these reptiles

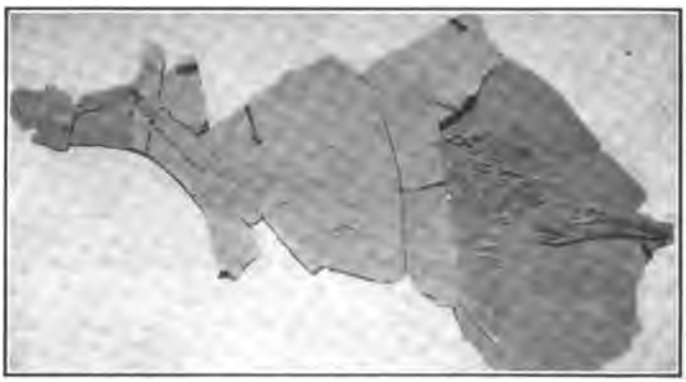


FIG. 1628. — Photograph of the same slab shown in Fig. 1627 after partial removal of the surface and exposure of the *Ichthyosaurus* (3.5 meters in length). (Photo by courtesy of Bernard Hauff, Holzmaden-Teck.)

were stranded on mud flats or in shallow lagoons where their bodies sank into the soft mud which enclosed and preserved them. Much wood is also found in the deposits, and this has often been changed,

FIG. 1629. — The same *Ichthyosaurus* skeleton, 3.5 meters long, shown in the preceding views, after complete preparation and mounting. (Photo by courtesy of Bernard Hauff.)

in part, at least, to the mineral jet. Jet is found abundantly in the cliffs of Liassic sandstones and shales which face the North Sea near the ancient town of Whitby in England (Fig. 292, p. 350, Pt. I), and here, too, many of the ammonites of the Lias

FIG. 1630. — Palæontological Laboratory of Bernard Hauff in Holzmaden-Teck, Württemberg. Mr. Hauff is engaged in the preparation of the skull of *Ichthyosaurus ingens*. 1909.

may be obtained. These are again found in great variety and perfection in the outcrop of Liassic strata near Stuttgart in Württemberg. In some sections of north Germany the Lias is coal-bearing.

Middle Jurassic or Dogger. — The Liassic transgression came to an end by the partial emergence, in mid-Jurassic time, of many parts of northwestern Europe, and the erosion of formations previously deposited. Elsewhere, as in northeastern England, estuarine and fresh-water conditions came into existence, and coal deposits were formed in some sections (Scotland). In southern England eolian rocks, partly oölitic and partly of broken shells, etc., formed the first of the great Oölite series which characterize the Middle and Upper Jurassic of that country (Fig. 1631,

Fig. 1631. — Oölitic millepore limestone, showing the characteristic cross-bedding of some of the Jurassic Oölites of England. Ions-Nab, south of Scarborough, England. (M. I. Goldman, photo.)

see also Figs. 719 *a*, *b*, pp. 812, 813, Pt. I). In southern France, on the other hand, limestones continued to be deposited, while in Luxemburg and southern Germany sands with iron oölites accumulated. It is these iron oölites which have generally stained the Dogger sandstones an ochery color, on which account the name Brown Jura has been applied to the series.

The Middle Jurassic period may be summarized as one of oscillatory conditions with partial emergence of some of the old land masses (central France, Bohemia, British Isles), so that many local breaks in the succession of deposits are found in the neighborhood of these masses, while elsewhere shallow sea, estuarine, and continental deposits were forming. In other regions again, there was an advance of the Dogger seas, so that lands were flooded which during Liassic time were dry (Fig. 1632). This transgression extended widely over Germany and Russia, especially in later Dogger time (Callovian) when the North Sea basin again became confluent with the north Russian sea across north Germany. The shoaling or emerging conditions were favorable for the formation of iron ores, probably in large part as bog iron ore, though some of the

FIG. 1632. — Unconformable contact between the horizontal Jurassic (Lower Oölite) deposits and the steeply inclined Ordovician beds (sandstone of May). At May (Calvados), France. (After Haug.)

mineral was no doubt precipitated from iron solution brought into the sea.

Upper Jurassic or Malm. — With the opening of Upper Jurassic time, the seas over Europe again began to transgress as they did over North America. This resulted in widespread deposition of Upper Jurassic rocks which are calcareous over large areas. Corals grew in abundance in these waters, even in England, where their presence in great coral banks has given rise to the name Corallian for the lower subdivision of the Malm. The maximum transgression occurred in Kimmeridgian time when the sea spread far and wide over Europe, so that in many sections the series begins with this division.

The Upper Jurassic limestones are finely exposed in the great limestone cliff which extends across southern Germany and is

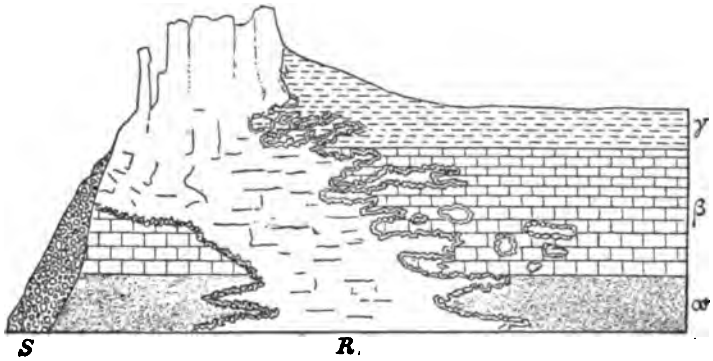


FIG. 1633. — Sponge reef in the Lower White Jura of Swabia. *R*, structureless reef limestone; *α*, *β*, *γ*, associated bedded limestone of the White Jura; *S*, talus. (After E. Fraas, from *Principles of Stratigraphy*.)

known as the Swabian Alp. This is an erosion remnant (cuesta), as already noted, formed by the removal of the former northward extent of these strata. Examinations of this limestone show that in the lower part there are many large reef-like masses composed chiefly of the remains of sponges, some of which are preserved with wonderful perfection of detail (Fig. 1633). In the higher divisions of this series other reefs, largely composed of shells (*Diceras*, Fig. 1634) and calcareous algæ are found, and in the lagoons between these reefs very fine lime muds were accumulating in beds up to 6 inches or more in thickness (Figs. 1635 *a–c*). These are the famous lithographic

FIG. 1634. — *Diceras arietinum*. A peculiar pelecypod with twisted valves, characteristic of the reef facies of the Upper Jurassic (Malm).

FIG. 1635 *a*. — Section of a lagoon in the Jurassic reef-rock of Solnhofen, showing the formation of the fine-grained lithographic limestone. (After Walther; from *Principles of Stratigraphy.*)

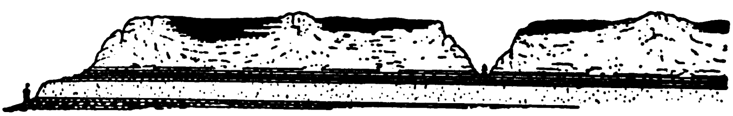


FIG. 1635 *b*. — Section through the Jurassic reefs of the Altmühl in the Pappenheim-Eichstädt region near Solnhofen, Bavaria, showing the structureless reef-rock and the thin-bedded platy limestones of lagoon origin, lying in depressions of this rock. (After Walther; from *Principles of Stratigraphy.*)

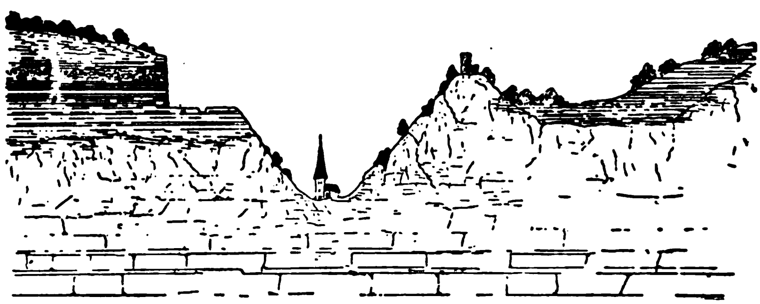


FIG. 1635 *c*. — Reef-rock (Franken dolomite, Jurassic) of Kelheim, Bavaria. The thin-bedded " Platten Kalke" are shown by horizontal lines; the reef-rock is structureless; in the upper left hand of the section the strata show distortion due to gliding deformation. (After Walther; from *Principles of Stratigraphy.*)

FIG. 1636. — A horse-shoe crab (*Limulus*) and the marks of its death struggle, showing that it was left stranded on the mud which formed the Jurassic lagoon deposits of Solnhofen. (After Walther; from *Principles of Stratigraphy.*)

limestones quarried at Solnhofen (Fig. 475, p. 572, Pt. I) and elsewhere in Bavaria, and formerly sent to all parts of the world where lithographic work was done. In the more argillaceous beds, which

FIG. 1637. — *Petalia longialata*, a dragon-fly from the Jurassic lithographic slates of Solnhofen, Bavaria. (From Zittel.)

separate the usable layers and which, because of the thin sheets into which they split, are much used for roofing purposes, the remains of both marine and land animals are found, preserved often in the most wonderful perfection (Fig. 1636, see also Fig.

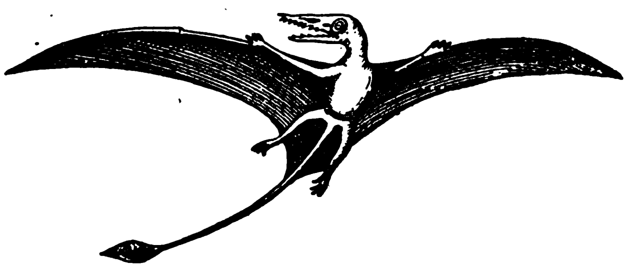


FIG. 1638. — Restoration (reduced) of *Rhamphorhynchus phyllurus*, from the lithographic limestone series (interbedded platy beds) of Solnhofen, Bavaria. (After Marsh.)

937, p. 150). The land animals are all of types which could fly, and which were at home elsewhere. Among them are dragon-flies with their wings fully spread (Fig. 1637). Here too are found the remains of flying reptiles (*Rhamphorhynchus*, etc., Fig. 1638) and those of the oldest known bird, the *Archæopteryx*, of which, how-

FIG. 1639. — *Archæopteryx lithographica*, from the lithographic limestone series of the Solnhofen region, Bavaria. Specimen in Berlin Museum. Reduced.

ever, only two specimens are extant (Fig. 1639). These animals came from the not very distant lands to the north, fell exhausted upon the mud flats exposed at low tide, and became

FIG. 1640. —Section in the Isle of Portland, Dorset, showing the Jurassic dirt-bed and ancient forest. (After Buckland and De la Beche; from Lyell.)

buried by fine sediments as the flats were again covered by the rising tide.

Toward the close of the Jurassic, emergence again took place. Forests began to grow where formerly the sea waves rolled, and rivers began to spread out their sediments. The Purbeck beds of

FIG. 1641. — Gorge of the Ardèche, near Ruoms, France, cut in the Jurassic (upper Oölite), limestones. (After Haug.)

England contain several old forest soils with tree stumps still standing and buried in fresh-water muds and limestone of later Jurassic age (Fig. 1640). These muds also contain the remains of fresh-water Mollusca (*Unio*, *Vivipara*, *Planorbis*, etc., Figs.

772, 773, pp. 51, 52), of fish, crocodiles, turtles, and dinosaurs, while the presence of an occasional oyster bed indicates temporary returns of the sea. Similar emergent conditions with the deposition of continental sediments are found in north Germany. In the Mediterranean basin, however, and over wide

FIG. 1642. — The Rock of Gibraltar. An eroded fault block of Jurassic limestone at the entrance to the Mediterranean Sea.

areas of Russia, continuous deposition of calcareous beds was going on throughout late Upper Jurassic time (Figs. 1641, 1642), and this continued apparently without break into the Lower Cretaceous (Comanchean). Thus what are believed to be continuous or transition formations were formed (*Tithonian* formation of the Alps, *Volgian* formation of Russia).

THE JURASSIC OF OTHER COUNTRIES

Asia. — Marine Jurassic deposits are found in Siberia, where the Upper Jurassic sea transgressed over the plains of the Siberian basin, covering vast areas. These deposits enclose shells of the pelecypod *Aucella* (Fig. 1651) and the cephalopod *Belemnites* (Fig. 1673), together with other forms which constitute an essentially distinct and apparently cool water type of life. This was the Boreal or Russian fauna which, we have seen, also entered the waters of western North America. During Liassic time, however, a large part of northern Asia was the site of continental sedimentation and the formation of extensive coal deposits. These are known from the Altai Mountains, southern Mongolia and north China, Manchuria, and Shantung. In the extreme north (Lena River), east (Japan), south (Timor, Rotti, Borneo), and southwest (Persia, Caucasus, Anatolia), however, the **Lias** is represented by marine formations. Middle and Upper Jurassic beds are well developed in India (beginning with Bathonian), these beds including many European species of fossils. They are also found in the Caucasus, in Syria, and again in Japan and elsewhere.

Australia, etc. — Marine Lias is found in New Zealand, and Middle Jurassic beds occur in western Australia. In the interior, coal-bearing continental deposits were formed at this time.

Africa. — North Africa belonged to the Balearic and Mediterranean basins, and partook to some extent of their deposits. Marine deposits of middle and late Jurassic age are also found on the eastern and southern coasts and on western Madagascar.

Characteristic Fossils of the Jurassic

Plants. — The most important and widespread types of Jurassic land plants are cycads (*Zamites*, *Podozamites*, etc., Fig. 815, p. 84); other types of land plants belong to the equisetiæ, the ferns, and the conifers. On the whole the flora is closely related to that of the Rhætic and continuous with little change into the Comanchean.

Fig. 1643 *a*. — A Jurassic sponge (Lithistida), *Cnemidiastrium rimulosum*. Upper Jurassic (Kimmeridge.) Europe.

Fig. 1643 *b*. — Isolated spicular bodies of a Jurassic silicious sponge (Lithistida), *Epistomella clivosa*. White Jura.

Marine Invertebrates. — **Sponges** are very abundant in the European Upper Jurassic, where they are often reef-building. They include most frequently Lithistid (*Cnemidiastrium*, *Epistomella*, Fig. 1643 *a*, *b*) and Hexactinellid types (*Craticularia*). **Corals** also abound, especially in the European Upper Jurassic, where compound reef-building types predominate (*Thamnastræa*, Fig. 1644; *Isastræa*, Fig. 1645; *Thecosmilia*, Fig. 1646, etc.), forms already represented in the Triassic, as is also the single coral *Montlivaultia* (Fig. 1647). **Brachiopods** are represented by only a few generic types, among which *Rhynchonella* (Fig. 1648 *a*, *b*) and *Terebratula* (Fig. 1649) are the most charac-

FIG. 1644. — *Thamnastræa prolifera*, a characteristic coral of the Upper Jura (Malm). *A*, compound corallum, two-thirds natural size; *w*, epitheca; *B*, lateral view (section) of two adjoining septa of neighboring corallites (×3); *m*, junction point of septa; *t*, trabeculæ; *p*, pores. (After Steinmann.)

FIG. 1645. — *Isastræa helianthoides*. Upper Jurassic (Tithonian) of Europe.

FIG. 1646. — *Thecosmilia trichotoma*. Upper Jurassic (Tithonian) of Europe.

FIG. 1647. — *Montlivaultia caryophyllata*. (After d'Orbigny.)

FIG. 1648 *a*. — *Rhynchonella quadriplicata*. Brown Jura, Württemberg.

teristic. One of the most striking forms of the Upper Jurassic is *Terebratula diphya* (Fig. 1650) which is deeply divided along the middle, and reunited at the base, so that the shell is characterized by a hole through the center. Among **Pelecypods** the remarkable curved *Gryphæa* (*G. arcuata*, etc., Fig.

FIG. 1648 *b.* — *Rhynchonella lacunosa*, interior of brachial valve. Upper Jurassic of central Europe.

FIG. 1649. — *Terebratula phillipsi*, a Middle Jurassic brachiopod from Switzerland. (From Zittel, *Grundzüge.*)

FIG. 1650. — *Terebratula* (*Pygope*) *diphya* (slightly reduced). Upper Jurassic (Tithonian) of Europe, etc.

FIG. 1651. — *Aucella mosquensis*. Upper Jurassic (Tithonian) of Europe.

FIG. 1652. — *Gryphæa arcuata* (slightly reduced). Lower Jurassic (Liassic) of Europe.

FIG. 1653. — *Opis goldfussiana*. Upper Jurassic (Tithonian) of Europe.

1652) is especially characteristic of the Lower, while *Aucella* (Fig. 1651), *Opis* (Fig. 1653), and the remarkable *Diceras*, with both valves spirally twisted (Fig. 1634), characterize the Upper Jurassic. *Trigonia* (Fig. 1654) and plicated oysters (Fig. 1655) are very characteristic forms. **Gastropods,**

FIG. 1654. — *Trigonia navis* (reduced), Middle Jurassic (Dogger) of Europe.

FIG. 1655. — *Ostrea marshi* (reduced), Middle Jurassic (Dogger) of Europe.

FIG. 1656. — *Pteroceras oceani*, Upper Jurassic (Kimmeridgian) of Europe.

a *b*

FIG. 1657. — *Nerinea tuberculosa.* *a*, entire shell showing aperture; *b*, longitudinal section of the same.

too, are numerous, and among them the genera *Pleurotomaria*, *Pteroceras* (Fig. 1656), and *Nerinea* (Fig. 1657 *a*, *b*) are very characteristic, the last especially being very abundant in the Middle Jurassic beds. But by far

FIG. 1658. — A primitive ammonite (*Psiloceras planorbis*) with a simple suture and a shell only slightly modified by gentle undulations or ribs. This form occurs in the Lower Jurassic (lower Lias) of Württemberg and shows ancestral characteristics which appear in several evolutionary series of Jurassic ammonites.

the most important index fossils are the **Ammonites**, of which an astounding number of genera and species has become known from the Jurassic, where this group was at the height of its development. Most characteristic of the Lias are the round or angular whorled, scarcely embracing (evolute), simply ribbed genera, such as *Psiloceras* (Fig. 1658, smooth or with very fine ribs),

FIG. 1659. — *Ammonites* (*Schlotheimia*), *angulata*, lower Lias, Württemberg.

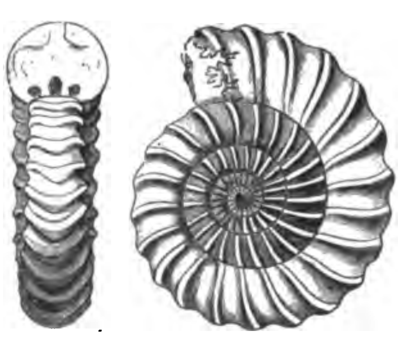


FIG. 1660. — *Ammonites* (*Ægoceras*) *capricornis*, middle Lias, Württemberg.

Schlotheimia (Fig. 1659, with strong ribs interrupted by a furrow on the ventral or outer side), *Ægoceras* (Fig. 1660, with ribs flattened on venter), *Arietites* (Fig. 1661, with ribs interrupted by strong keel bounded by furrows), and *Hildoceras* (Fig. 1662, with additional lateral grooves). Of the types with

FIG. 1661. — ***Arietites bucklandi*** ($\times\frac{1}{1.5}$), Lower Jurassic (Liassic) of Europe.

FIG. 1662. — ***Harpoceras (Hildoceras) bifrons*** ($\times\frac{1}{3}$), Lower Jurassic (Liassic) of Europe.

FIG. 1663. — ***Amaltheus margaritatus*** ($\times\frac{1}{3}$), Lower Jurassic (Liassic) of Europe.

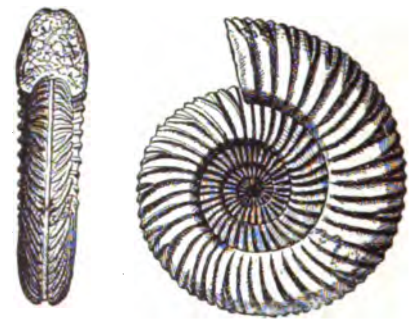


FIG. 1664. — ***Parkinsonia parkinsoni*** ($\times\frac{1}{3}$), Middle Jurassic (Dogger) of Europe.

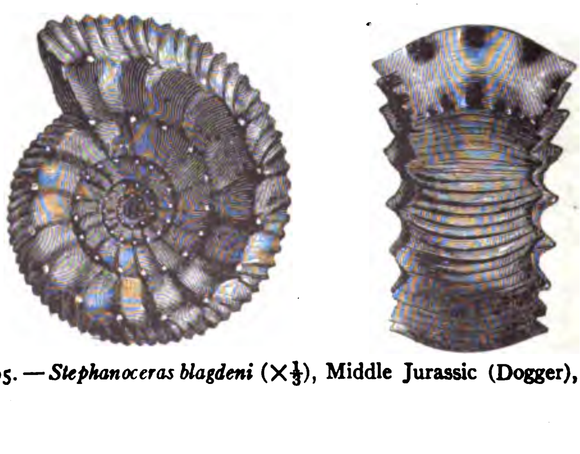


FIG. 1665. — ***Stephanoceras blagdeni*** ($\times\frac{1}{3}$), Middle Jurassic (Dogger), Europe.

laterally compressed and more deeply involute whorls, the genera *Amaltheus* (Fig. 1663), with its rope-like keel, and *Phylloceras* (Fig. 905, p. 134), smooth, with leaf-like sutures, are most characteristic. The most typical Middle

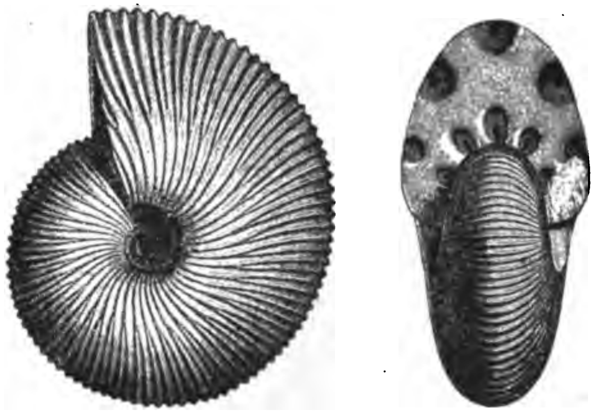


Fig. 1666. — *Ammonites (Macrocephalites) macrocephalus*, Jurassic (Callovian), Württemberg.

Jurassic genera are *Parkinsonia* (Fig. 1664, with bifurcating ribs interrupted by a pronounced groove on the venter), *Stephanoceras* (Fig. 1665, vertically compressed with strong bifurcating or trifurcating ribs which cross the venter and are often spinose), *Macrocephalites* (Fig. 1666, thick, close-coiled forms with numerous fine, often dividing ribs), and *Cosmoceras* (Fig. 1667, with dividing

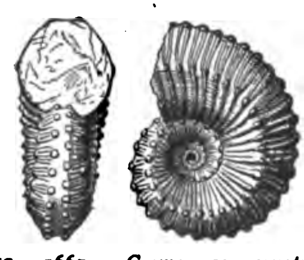


Fig. 1667. — *Cosmoceras ornatum*, Middle Jurassic (Dogger) of Europe.

Fig. 1668. — *Perisphinctes tiziani*, Upper Jurassic (Malm) of Europe.

and strongly-noded ribs, interrupted by a furrow at the venter). Characteristic of the Upper Jurassic are *Perisphinctes* (Fig. 1668, open-whorled with ribs regularly bi- or trifurcating on the ventral side), *Oppelia* (Fig. 1670, laterally compressed, deeply involute, mostly with faint ribs), *Aspidoceras* (Fig. 1671, open-coiled with few coarse ribs strongly spinose), and the rather close-coiled *Virgatites* (Fig. 1672) with numerous bundles of ribs, which is especially characteristic of the boreal Jurassic. There are, of course, many other less readily characterized forms, all of them having highly complex ammonite sutures.

Another very important group of cephalopods of the Jurassic is that of the **Belemnites**, of which the cigar-shaped calcareous guard is most generally preserved, showing, when complete, the deep apical depression in which the

FIG. 1669.—*Idoceras soteloi*, a characteristic Middle Jurassic ammonite of Mexico, etc. (After O'Connell.)

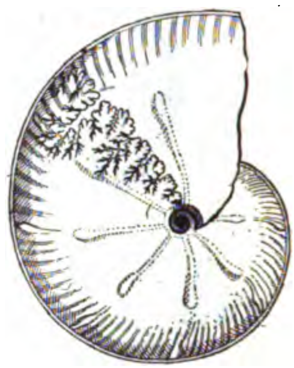


FIG. 1670.—*Oppelia tenuilobata*. Upper Jurassic (Malm) of Europe.

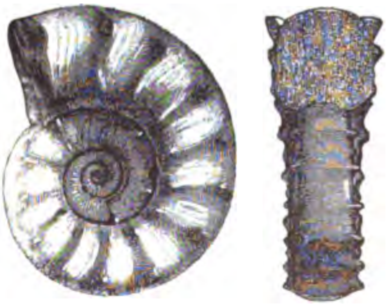


FIG. 1671.—*Ammonites (Aspidoceras) perarmatum*, about $\frac{2}{3}$ natural size. Jurassic (Oxfordian) Europe.

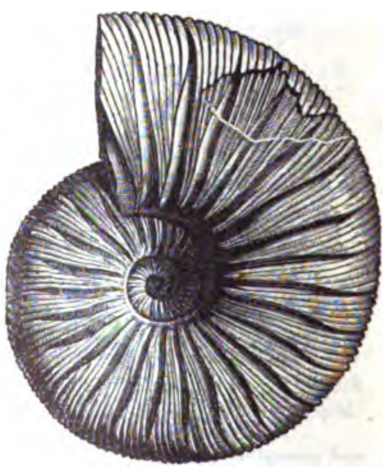


FIG. 1672. — *Virgatites virgatus*, Jurassic (Tithonian).

conical-chambered shell is normally situated. These forms vary greatly in shape and in size, some species reaching a length of a meter. A number of these types are shown in Figure 1673.

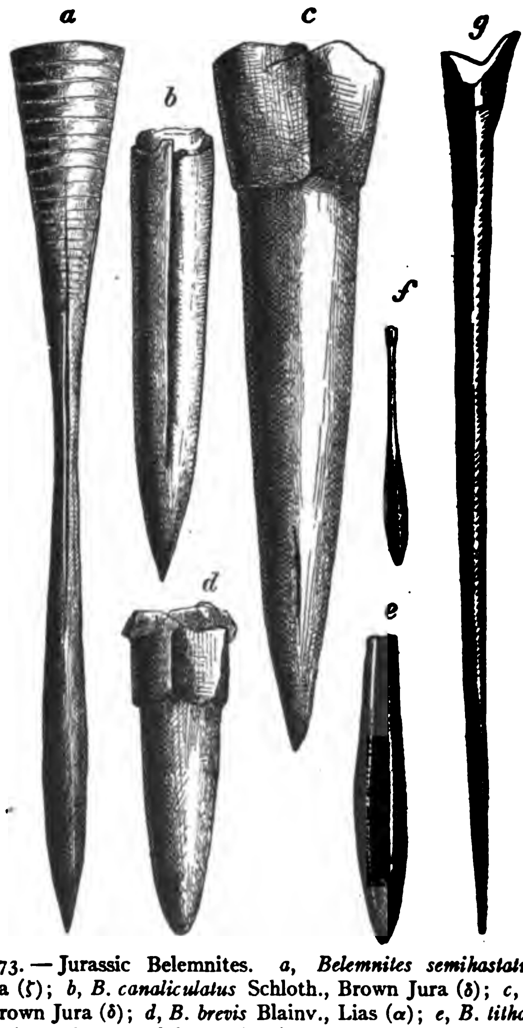


FIG. 1673. — Jurassic Belemnites. *a*, *Belemnites semihastatus* Quenst., Brown Jura (ζ); *b*, *B. canaliculatus* Schloth., Brown Jura (δ); *c*, *B. giganteus* Schloth., Brown Jura (δ); *d*, *B. brevis* Blainv., Lias (α); *e*, *B. tithonicus* Opp., Tithonian; *f*, *B. clavatus* Blainv., Lias (γ); *g*, *B. acuarius-tubularis* Blainv., Lias (ε). (From Haas' *Leitfossilien.*)

The **Crustacea** have very much the modern appearance, with lobster-like types predominating (Figs. 1674, 1675). The **Echinoderms**, finally, are represented by *Pentacrinus* (Fig. 1676) with five-lobed stem joints marked by

FIG. 1674.—A Jurassic lobster, *Eryon arctiformis*, dorsal aspect. (After d'Orbigny.)

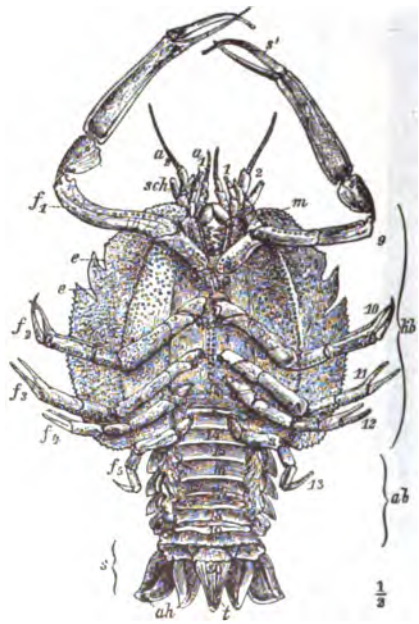


FIG. 1675. —*Eryon propinquus*, Jurassic (Malm) Solnhofen. Ventral view; *kb*, Cephalothorax; *ab*, abdomen; *s*, caudal fin; *t*, telson; *ah*, swimming appendages of the 19th segment; 1–20, body segments; a_1a_2, antennæ; f_1–f_6, thoracic (walking) legs; *r*, rostrum; *sch*, scale of the second antenna; *s*, lobes of carapace; *s'*, pincers of first pair of thoracic legs; *m*, mouth. (From Steinmann.)

numerous root-like cirrhi, and with frequently divided arms; by *Apiocrinus* (Fig. 1677) with round stem-joints gradually enlarging to the full size of the calyx; by a small floating crinoid, *Saccocoma* (Fig. 1678), which occurs in great numbers on the thin platy layers of the Solnhofen lagoon deposits, and by numerous sea urchins, especially the regular *Cidaris* (Fig. 1679) with its large club-shaped spines (Fig. 958 *a*, *b*, pp. 163, 164).

FIG. 1676. — *Pentacrinus fasciculosus*, calyx with arm and part of stem, lateral and summit view of stem joints. (After d'Orbigny.)

FIG. 1677. — *Apiocrinus roissyanus*, entire individual. (Stem shortened.) (After d'Orbigny.)

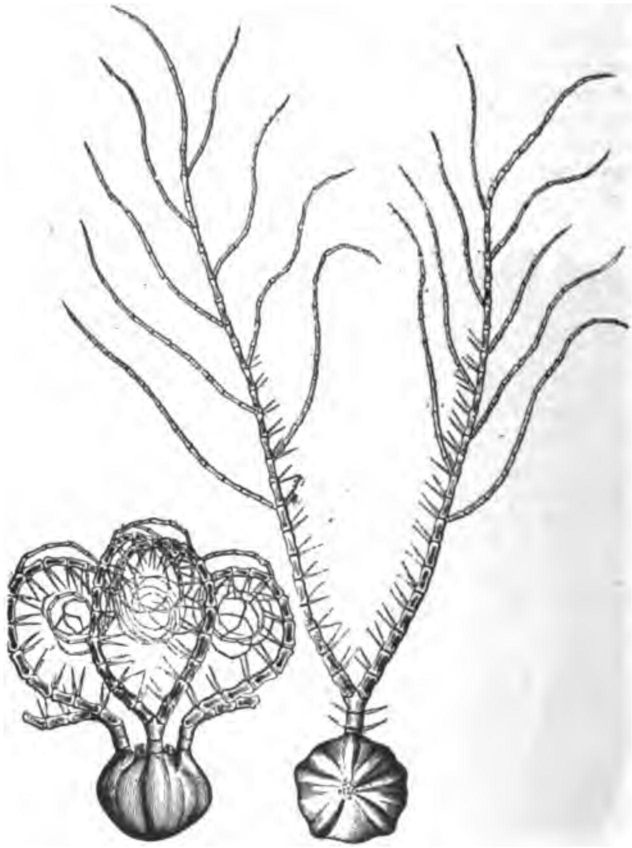


FIG. 1678. — *Saccocoma pectinata*, enlarged. (After d'Orbigny.)

FIG. 1679. — *Cidaris coronata*. Upper Jurassic (Kimmeridgian), Württemberg.

Insects. — These are numerous, about 1000 species being known. They are of the modern types, though of course of distinct genera. Dragon-flies (Fig. 1637) and beetles were abundant, but true butterflies were as yet rare or wanting. Other types included cicadas, grasshoppers, locusts, cockroaches, ants, and termites. The species of the Lias were generally small and have been regarded as dwarfed forms due to coolness of climate, but in later Jurassic time they were large, though not reaching the size of the Palæozoic types.

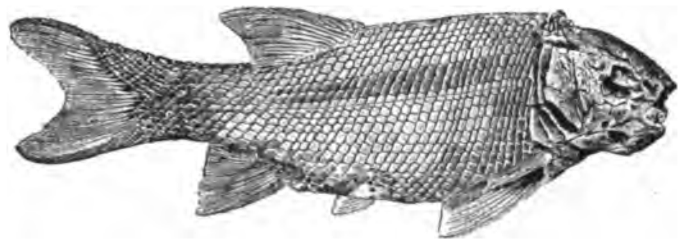


FIG. 1680. — *Lepidotus notopterus* ($\times\frac{1}{10}$), a Jurassic ganoid fish.

Vertebrates. — **Fish** were abundant in the Jurassic seas and probably also in the rivers. They included even-tailed ganoids (Fig. 1680), sharks, rays, (Fig. 1681) and numerous bony fishes (teleosts). **Reptiles** were, however, the most abundant and diversified of the vertebrates. These included the marine *Ichthyosaurus* (Fig. 1629) and *Plesiosaurus* (Fig. 1682), the aërial pterosaurs (*Pterodactylus*, Fig. 1683; *Rhamphorhynchus*, Fig. 1638), numerous turtles (Fig. 1684), crocodiles (*Mystriosaurus; Teleosaurus*, Fig. 1784), and especially the terrestrial dinosaurs, which reached their greatest modification in form and their most gigantic size toward the close of the Jurassic or in early Comanchean time. These will be more fully considered in Chapter XLIV. Most remarkable, too, are the remains of the earliest known **Bird**, *Archæopteryx* (Fig. 1639), from the lithographic rocks of the Solnhofen region in Bavaria. This bird still retained many reptilian characters, such as the long vertebrated tail, the

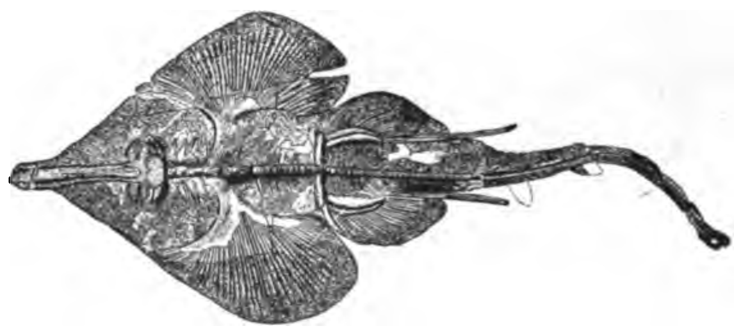


FIG. 1681. — *Rhinobatis mirabilis* (male, $\frac{1}{15}$ natural size). Uppermost Jurassic (Lithographic limestone), Eichstätt, Bavaria.

well-developed teeth, etc. (See further Chapter XLIV.) Finally, the occurrence of small primitive **Mammals** should be noted, though these, like the birds, are of rare types.

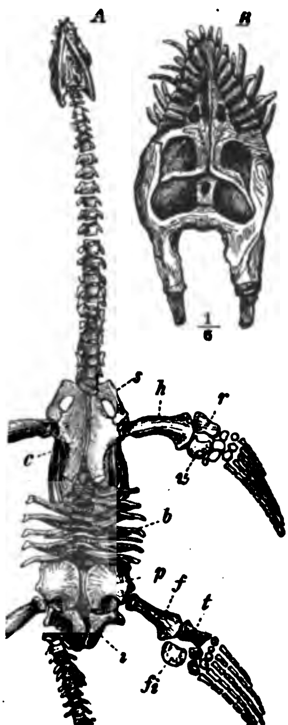


FIG. 1682. — *Plesiosaurus dolichodeirus* Conyb., L. Lias, England. *A*, ventral aspect of skeleton ($\times\frac{1}{18}$); *B*, skull from above ($\times\frac{1}{6}$). *A*, eye socket; *b*, abdominal ribs; *c*, coracoid; *f*, femur; *fi*, fibula; *h*, humerus; *i*, ischium; *p*, pubis; *r*, radius; *s*, precoracoid; *t*, tibia; *u*, ulna. (After Steinmann.)

MOUNTAIN-MAKING AT THE CLOSE OF THE JURASSIC

Tectonic disturbances affected the Triassic rocks of eastern North America during and toward the close of the Jurassic, and produced an extensive series of faults which dislocated these strata, but gave rise to no great mountain chains. Subsequent erosion removed the upfaulted blocks, preserving only the depressed ones in a series of isolated areas. More pronounced disturbances, however, took place in western North America, where the Triassic and Jurassic formations of the Cordilleran geosyncline were folded into the Cordilleran Mountain ranges, of which the Sierra Nevadas are a remnant, though these were uplifted again in a later period. Not all of the strata of the geosyncline were folded. Some, like those of the Humboldt Mountains of Nevada, suffered only bodily uplift. The Palæocordilleran ranges had, by this time, become much eroded. Indeed, they may have been largely peneplaned, but the basin to the east of them still continued to be the site of active deposition in the succeeding periods.

To the west of the Cordilleran range of folded older Mesozoics a new geosyncline was now formed in the region of the oldland, and it was in this western depression, bounded on the west largely by lands now submerged beneath the Pacific, that the Comanchean and Cretaceous strata accumulated.

Accompanying the folding was an immense outpouring of lava,

FIG. 1683. — *Pterodactylus crassirostris*. (After d'Orbigny.)

FIG. 1684. — *Eurysternum wagleri*, Upper Jurassic, Solnhofen; from above: c_1, c_4, c_8, costal plates; *hp*, hypoplastron; *hs*, hyoplastron; *il*, ileum; m_1, m_5, m_8, m_{11}, marginal plates; n_1, n_4, n_8, neural plates; *nu*, nuchal plate; *py*, pygal plate; on c_1, c_3, c_5, c_8, impressions of the horn shields are visible. (After Steinmann.)

and intrusion of igneous masses into the older rocks. This includes the lavas which now largely compose the Sierra Nevada Mountains, and others extending far to the north. These great igneous intrusions, by far the most extensive that had occurred since the beginning of Palæozoic time, were apparently responsible for the mineral-bearing waters and gases which enriched the Jurassic and older rocks of this region by their metallic wealth, and from which deposits the auriferous gravels were subsequently derived.

CHAPTER XLIII

THE CRETACEOUS SYSTEMS

Lower Cretaceous — Comanchean or Comanchic

Upper Cretaceous — Cretaceous proper or Cretacic

THE great chalk deposits of England, so well exposed in Shakespeare cliff at Dover (Fig. 201, p. 279, Pt. I) and on the Channel coast of France (Fig. 713, p. 807, Pt. I), form the type of the highest of the Secondary or Mesozoic deposits, though those originally so designated by Lehmann and Werner were sandstones and limestones of equivalent age in Germany. William Smith and his successors recognized that the chalk beds graded downwards into glauconitic chalk, and lower still into beds of glauconitic sands to which they applied the name *Greensands*. In the midst of this Greensand series lies a bed of clay, which is generally known as *Gault Clay* because it is cold and clammy to the touch. The Greensands below the Gault clay were designated *Lower Greensands* and those above it *Upper Greensands*. A fourth series of deposits, mainly of sands and clays, and now known to be a continental deposit, was recognized as forming the center of the Wold or Wealden district, in southeastern England, an eroded anticlinorium flanked on either side by uniclines of chalk, the so-called North and South Chalk Downs. To these beds, which underlie the Greensands and which, unlike those deposits and the chalk, contain no marine fossils, the name *Wealden beds* was given. These lithological divisions, still in general use in England, do not represent exact stratigraphic horizons, the Greensands rising in the geological scale towards the northwest (Fig. 1685).

As we have seen (*ante*, p. 18) the name *Cretaceous* was proposed for these rocks by Omalius d'Halloy in 1822, being derived from the Latin word *creta* (chalk), and it was soon recognized that these deposits could be divided into two divisions, an Upper and a Lower Cretaceous. In Germany the beds included in these systems were first known as *Quader Sandstein* or sandstone which permitted quarrying in large blocks (*Quader*), and *Pläner Kalk* or thin-bedded limestone. These were the original Secondary rocks of the Saxon geologists. A third lithologic type, the *Hils*, essentially a shore facies at the base of the series, was also distinguished.

It was, however, in France and Switzerland that the fullest representation of the Cretaceous deposits was found, and in these regions the formations are largely marine limestones. The labors

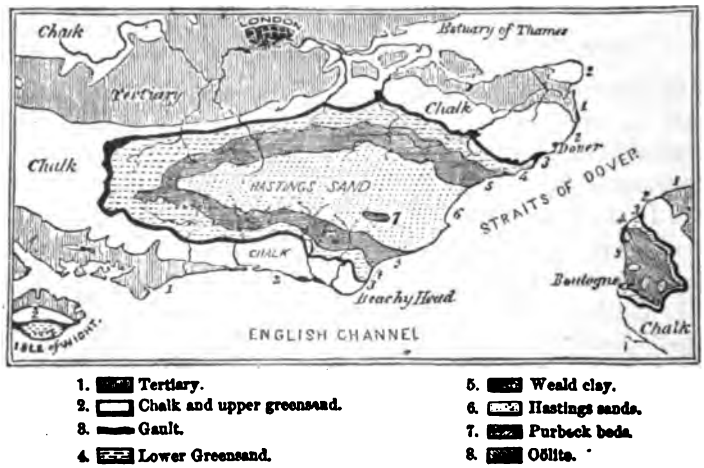


FIG. 1685. — Geological map of southeastern England and part of France, exhibiting the denudation of the Weald. (After Lyell.)

of Alcide d'Orbigny and his successors have demonstrated that a more precise subdivision into thirteen groups or stages was possible, of which seven are comprised in the Upper, and six in the Lower Cretaceous (see p. 685). These subdivisions have become the standard not only for Europe but for the rest of the earth as well.

In America for many years only Upper Cretaceous marine deposits were recognized, these being most typically developed in the Great Plains region and the Rocky Mountain front. When older marine deposits were found in Texas and Mexico they were grouped together under the name *Comanchean*, after the Comanche Indians, in whose territory the deposits were first studied (see *ante*, p. 19). This division is essentially equivalent to the Lower Cretaceous of Europe.

Subdivision of the Cretaceous in the Larger Sense

As in the case of the other Mesozoic systems, the Cretaceous standard is found in Europe, where the subdivision is generally into Lower and Upper Cretaceous. These divisions correspond essentially to the Comanchean and Cretaceous systems of American usage. Some European authors divide the Cretaceous as a whole into three divisions, Lower, Middle, and Upper, but this has not been adopted generally. The standard succession in western Europe is as follows:

Upper Cretaceous or Cretaceous proper (Cretacic)	Danian			Upper Cretaceous
	Mæstrichtian	Senonian		
	Campanian			
	Santonian			
	Coniacian or Emscherian			
	Turonian			Middle Cretaceous
	Cenomanian			
Lower Cretaceous or Comanchean (Comanchic)	Albian (Gault)			
	Aptian		Upper Neocomian	Neocomian or Lower Cretaceous
	Barremian			
	Hauterivian		Lower Neocomian	
	Valanginian			
	Berriasian (or Lower Valanginian)			

The North American Comanchean and Cretaceous

In North America the best known development, and in many respects the most complete, is found in the Mesozoic Piedmont basin east of the Cordilleran Mountain ranges, which had become an important area of deposition and had acquired the character of a broad interior geosyncline (Colorado geosyncline of Schuchert). In the western or Cordilleran (Pacific coast) geosyncline marine sediments were likewise accumulating in great thickness, while the eastern or Atlantic coast geosyncline was receiving marine sediments during (Upper) Cretaceous time. The Gulf embayment of Jurassic time still persisted. We will begin by considering the interior or Coloradoan geosyncline and the deposits of the Gulf embayment. The divisions recognized in the deposits of this region, which may be considered typical for North America, are as follows:

CRETACEOUS (Upper Cretaceous or Cretacic).
  Upper Cretaceous or Laramian.
  Middle Cretaceous or Montanan.
    Fox Hills group.
    Pierre group.
  Lower Cretaceous or Coloradoan.
    Niobrara group.
    Benton group.
  Basal (Dakota) sandstone series.
COMANCHEAN (Lower Cretaceous or Comanchic).
  Upper Comanchean or Washita.
  Middle Comanchean or Fredericksburg.
  Lower Comanchean or Trinity.

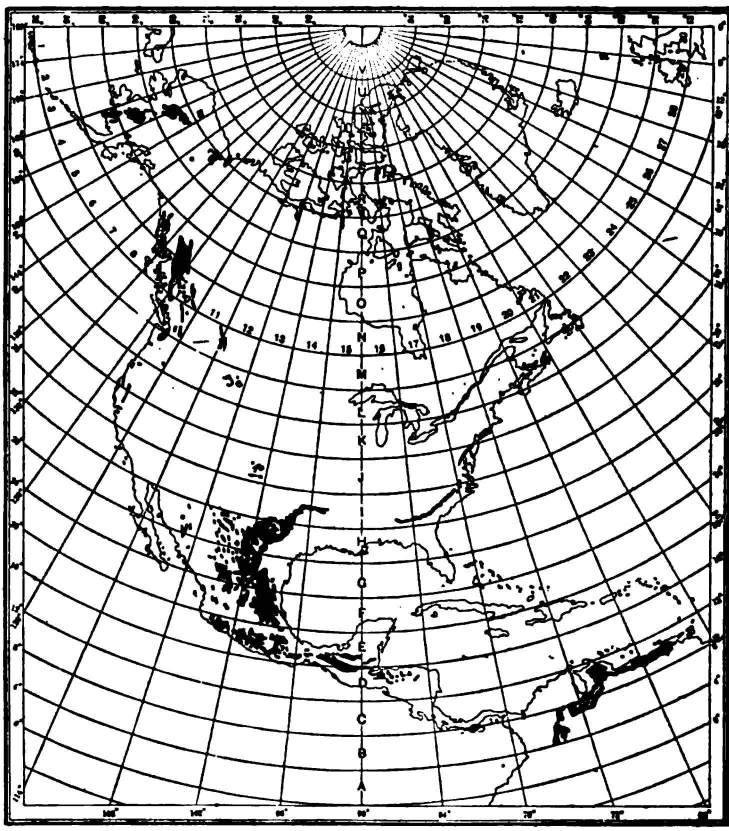


FIG. 1686. — Map showing the outcrops of Comanchean rocks in North America. (After Bailey Willis.)

Comanchean of the Gulf and Coloradoan Geosynclines

It will be recalled that during Jurassic time the Colorado basin was still separated on the south from the Atlantic or Gulf embayment, so that the marine sediments of the latter region were not in contact with the continental sediments formed in the Colorado basin, nor with the marine deposits which were formed in that basin in the sea (Logan Sea) which entered it from the north. By the opening of the Comanchean era, however, the barrier which separated these areas had become worn down so that the transgressing sea from the Gulf region was enabled to enter the northern interior basin.

The threefold division of the Comanchean is chiefly found in Texas, where, however, the series is only partially developed. In Mexico, on the other hand, a much more extensive series of deposits is known, and the three divisions are not so readily distinguished. These deposits, however, have been little studied as yet. The formations here are generally classed as Lower and Middle Cretaceous by the Mexican geologists, and they represent the European series up to and including the Cenomanian, while their Upper Cretaceous, which is essentially the equivalent of the American Cretaceous, is made to begin with beds of Turonian age. Haug and other European authors, however, include the Turonian in the Middle Cretaceous.

In the states of Vera Cruz and Puebla in Mexico the lower divisions (Eocretaceous of the Mexicans, essentially Trinity and older beds of American usage) consist of a great thickness of unfossiliferous, probably in the main continental, slates with some intercalated marine limestones, resting upon Jurassic or older rocks. In Zacatecas (Sierra de Mazapil), on the other hand, the Jurassic beds are concordantly succeeded by fossiliferous marls, followed by limestones 400 to 500 meters thick, and these in turn by argillaceous beds with marine fossils which mark the summit of the Eocretaceous (Trinity). These beds are followed by Mesocretaceous limestones (Fredericksburg and Washita) from 400 to 500 meters in thickness, which form the main limestone series of Mexico. Similar beds (*Orizaba limestone*, up to 600 meters thick) overlie the shales in Vera Cruz and Puebla.

This region comprises the most complete section of the Comanchean beds so far known. The waters in which they were deposited covered northern South America, as is shown by the occurrence of beds of this age in Colombia and Venezuela, where the shore facies of this sea are found, and where transgression is

FIG. 1687. — Palæogeographic map of North America showing the distribution of land and sea (black), in Comanchean time. (Original.)

indicated by overlapping of the higher divisions. Strata of the same age also occur in some of the West Indies, where they form a part of the much disturbed basal complex of Porto Rico. They probably occur in the other islands as well, although they have not yet been differentiated. From the fact that the fauna of all these beds is essentially that of western Europe, we may conclude that the Atlantic embayment, characteristic of this region in Jurassic time, had become a permanent feature as it is to-day, except that part of the islands and the adjoining coast were also submerged. However, the great depths of the present Gulf of Mexico and Caribbean Sea did not exist then, for the fossils and rocks indicate that the waters were shallow (Fig. 1687).

The main events of Comanchean time in this Gulf embayment were the transgression of the sea over the south central United States, followed by complete retreat from this same area. A similar advance and retreat probably characterized the Mexican region and the northern South American region, but the details

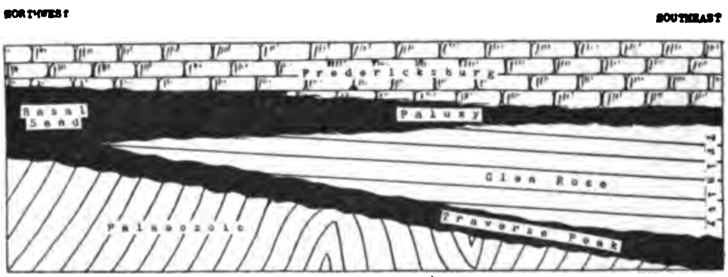


FIG. 1688. — Ideal section showing the relationships of the Trinity and Fredericksburg formations of the Texas Comanchean. The basal sandstone (in black) rises in the scale with the advance of the sea; the Paluxy sandstone (also in black) represents a combined sandstone of emergence and submergence. (Original.)

of this have not yet been determined. The transgression over the southern United States is clearly indicated by the northward and westward overlapping of the successive members of the Comanchean (Fig. 1668). Thus the Trinity division, characterized especially by the peculiar twisted pelecypod *Requienia* (Fig. 1689 *a–c*), covers only about the southern half of Texas, the old shore-line passing between the present Quitman and Finlay Mountains in western Texas and extending to some distance beyond Bisbee in Arizona, where 650 feet of limestones of this age rest apparently upon continental Comanchean beds (1800 to 1900 feet), which are in part red and lie unconformably upon the eroded edges of the folded Palæozoics, which there form a part of the old, worn-down Palæocordilleran Mountains. The transgression of the sea is also shown by the thinning of the limestone member of the

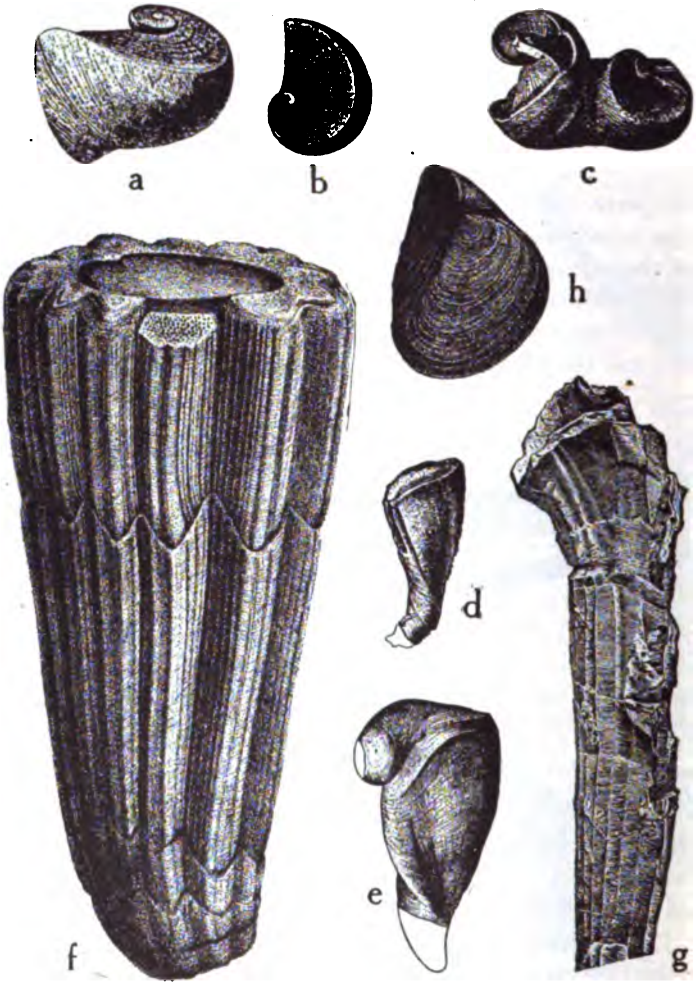


FIG. 1689. — Aberrant pelecypods of the Comanchic of the Gulf coast.

a, b, Requienia texana (Glen Rose and Fredericksburg of Texas and Mexico); *c, Requienia patagiata* (Fredericksburg, Texas and Mexico); *d, Monopleura marcida* (Glen Rose and upper Fredericksburg of Texas); *e, Monopleura pinguiscula*, showing the elongate right valve and twisted left valve (Glen Rose and upper Fredericksburg of Texas); *f, Radiolites texanus*, large lower valve made up of thick ridges of shell, the animal occupying the small central depression at the top; a small, conical upper valve not here shown, rests like a cap on top (Upper Fredericksburg of Texas); *g, Radiolites davidsoni* (Upper Fredericksburg of Texas); *h, Monopleura texana* (Fredericksburg of Texas and Mexico). All reduced. (I. F.)

Trinity (the *Glen Rose limestone*) northward and westward, this being 600 feet thick at Austin, but only about 5 feet at Twin Mountain in Erath county, and at Decatur, in Wise county, a hundred miles farther northeast.

In the region covered by these rocks the Trinity division begins with a basal sandstone which ranges up to 200 feet in thickness, and the top of the division is also formed by a sandstone showing a partial retreat of the sea after the first advance (Fig. 1688). The basal sandstone continues beyond the region of Trinity deposition and underlies the whole Comanchean series in the southern United States. From its character and extent it appears that we are dealing here with an old residual quartz-sand, deposited in pre-Comanchean time, and reworked by the advancing Comanchean sea, so that it became a basal sandstone for the entire overlapping series (Figs. 1690, 1691). This same sandstone continues northward over much of the Coloradoan geosyncline and constitutes the Dakota sandstone which rests on continental Comanchean or older rocks. The sea continued to advance northward until, by the end of Fredericksburg or the beginning of Washita time, it had covered all of Texas and Oklahoma, southern Kansas, southeastern Colorado, and eastern New Mexico as well as the greater part of Mexico (map, Fig. 1687). In this sea the great limestones of the period (*Comanche Peak* and *Edwards* of Texas, etc., part of *Orizaba* limestone of Mexico) were deposited, these being characterized by the peculiar rudistid pelecypods *Monopleura*, *Radiolites*, etc. (Figs. 1689 *d–g*), which are found in equivalent beds of southern Europe. These limestones also thin northward and westward, being 700 feet thick on the Rio Grande, 350 feet at

FIG. 1690. — Pulpit Rock, Kansas, an erosion monument cut from cross-bedded Dakota sandstone. (Photo by N. H. Darton from U. S. G. S.)

Austin, but only 25 feet thick on the Texas-Oklahoma boundary, where only the upper division is present, resting on 200 feet of basal sands. In southern Kansas the series is represented only by plant-bearing sandstones (*Cheyenne sandstones*), which rest disconformably upon the red beds, and are followed by a shell bed with *Gryphæa hilli*, a characteristic Fredericksburg fossil, and by the *Kiowa shales* with *Gryphæa corrugata* (Fig. 1692 *b*), representing the shore phase of the lower Washita series (regarded as uppermost Fredericksburg by some).

With the beginning of Washita time the sea again withdrew, and continental sands were spread over the emerging area by rivers

FIG. 1691. — Dakota sandstone showing effects of eolian erosion. Terrace in distance developed on basaltic lava flow of late Tertiary age. Union County, New Mexico. (Photo, B. Hubbard.)

and the wind. These sands (*Dakota sandstones*, etc.) rest on progressively higher members of the Washita series as they are followed southward, thus showing the characteristic features of an emerging series. While they follow upon the lowest Washita (*Kiowa* or *Kiamitia shales*) in Kansas, they are preceded by 840 feet of Washita shales and limestone in southern Oklahoma. The sandstone does not extend as far south as Austin, where the upper Washita limestones show evidence of erosion, a character, of course, quite consistent with the other evidence of emergence.

That the sea continued to submerge the greater part of Mexico, even during Washita time, while it retreated from the southern United States, is shown by the fact that the Washita formation is represented by great limestones (upper Orizaba or *Escamela limestones*) 600 meters in thickness. Finally, however, emergence also took place over much of Mexico, as is shown by the fact that these rocks were eroded before the next higher formations (Cretaceous) were deposited upon them. During the period of marine deposition (advance and retreat) in the Gulf region, the greater part of the Coloradoan geosyncline was above water, and continental beds (chiefly river flood-plain deposits, *i.e.*, the *Morrison*

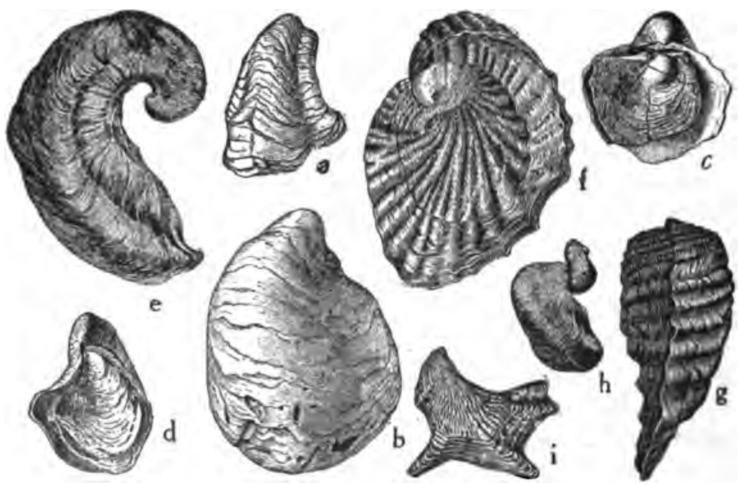


FIG. 1692. — Comanchean oysters and related pelecypods.

a, ***Gryphæa marcoui*** ($\times \frac{1}{2}$), Fredericksburg of Texas; *b*, ***Gryphæa corrugata*** ($\times \frac{1}{2}$), Comanchean of southern Kansas and Texas (*G. hilli* resembles the young of this species); *c*, ***Gryphæa washitaensis*** ($\times \frac{1}{2}$), Washita of Texas; *d*, ***Gryphæa navia*** ($\times \frac{1}{2}$), Washita, from Kansas to Mexico; *e*, ***Gryphæa mucronata*** ($\times \frac{1}{2}$), upper Washita of Texas; *f*, *g*, ***Exogyra texana*** ($\times \frac{1}{2}$), Comanchean of Mexico; *h*, ***Exogyra arietina*** ($\times \frac{1}{2}$), Washita of Texas; *i*, ***Ostrea quadriplicata*** ($\times \frac{1}{2}$), Washita of Texas, Oklahoma and Kansas. (I. F.)

formation) were laid down, while still farther north in Canada other continental beds enclosing coal (*Kootenai* formation) accumulated.

Comanchean of the Post-Appalachian Geosyncline

It has been stated that upon the folding of the strata of the Appalachian geosyncline, a new geosyncline came into existence to the east of the Appalachian Mountains in which the Triassic strata were deposited, though only the Upper Triassic Newark series is known. In Jurassic time this geosyncline seems not to have received any deposits, or at any rate they are not known, but in Comanchean and Cretaceous time this eastern geosyncline again became the site of depression and of active deposition.

It is generally held that the Comanchean and Cretaceous strata of the present Atlantic coastal plain were deposited on the margin of the open Atlantic, partly above and partly beneath its waters. There are, however, certain objections to this view, chief among which is the difference in the fauna of the Cretaceous beds of the present Atlantic and Gulf Coastal plain and that of the islands immediately to the south, as will be more fully considered under the discussion of the Cretaceous. Furthermore, there is evidence that the Cretaceous strata of the Greater Antilles were formed in the neighborhood of a land mass. For these and other reasons we may tentatively assume that a land barrier, the unsubmerged remnant of Appalachia, extended east and west from Texas to Florida and thence northeastward for an unknown distance (see map, Fig. 1687), and that between it and the Appalachian Mountains lay a broad and rather shallow geosyncline which extended from Massachusetts to Texas, where it became confluent with the Colorado geosyncline. If this were the case in Cretaceous time, the geosyncline probably existed also in Comanchean time, although during that era it was chiefly the site of continental sedimentation. It should, however, be distinctly understood that the existence of such a continuous land mass is by no means proved, but its presence would account for many phenomena otherwise difficult of explanation. But whether marginal to the Atlantic, or separated from it by a remnant of the Appalachian oldland, this new Appalachian geosyncline was the site of deposition of several thousand feet of clastic strata, of which those belonging to the Comanchean were wholly non-marine. The following formations occurring in this region are included in the Comanchean system.

SUPERFORMATION

Raritan sands (Dakota) followed by marine Cretaceous beds.

Thickness of Raritan . . . . 400 feet

Hiatus and Disconformity

COMANCHEAN BEDS

Patapsco formation, ranging to . . . . 200 feet

Highly colored and variegated clays and lighter colored sandy clays and sands. Angiosperm flora.

Hiatus and Disconformity

Arundel formation (Upper Neocomian), ranging to . . . . . . 125 feet
Chiefly clays, locally iron-bearing and lignitic, flora similar to Patuxent, remains of Dinosaurs.

Hiatus and Disconformity

Patuxent formation (Lower Neocomian), ranging to . . . . . . 350 feet
Chiefly arkose sands often cross-bedded with small masses of clay and an early Comanchean flora.

Unconformity

SUBFORMATION. Crystalline schist, etc., or locally, Triassic rocks.

These formations are river flood-plain and alluvial fan deposits, with occasionally clays that represent swamp- and lake-sediments. The succeeding Raritan sands are often lignitic, and appear to be in part of eolian origin. They contain the plants characteristic of the Dakota sandstone of the interior.

The Cretaceous (Upper Cretaceous) Deposits of the Gulf and Coloradoan Geosynclines

The Cretaceous deposits of these regions formerly extended continuously from Mexico into Canada and perhaps to the Arctic region, but they have been removed by post-Cretaceous erosion in northern Texas, Oklahoma, and New Mexico so that they now appear in two disconnected areas. From eastern Texas the deposits extend continuously beneath the Tertiary and younger rocks throughout the Neo-Appalachian geosyncline to New Jersey and Long Island, cropping out along the northern edge of the coastal plain wherever the Tertiary strata have been eroded.

Throughout Mexico and the southern United States, so far as known, the Cretaceous rests disconformably upon the Comanchean, the latter being more or less eroded. This means, of course, that the sea withdrew from this entire region at the end of Comanchean time and that wherever the continental Dakota sands did not act as a protecting cover, erosion removed a part of the older series before the readvance of the sea. It is probable that the sea did not withdraw from the center of the east-and-west Gulf geosyncline; but the northern portion of this geosyncline, now represented by the Greater Antillean islands, was probably in part uncovered, though at present we do not know what the relationship of the Comanchean and Cretaceous strata of these islands is. In some cases, however (Havana, Cuba, etc.), it is known that the Cretaceous beds lie directly upon old crystallines.

In parts of Cuba the basal Cretaceous beds are either unfossiliferous arkoses or coal-bearing continental beds followed by shales and limestones with marine fossils. This indicates the transgression

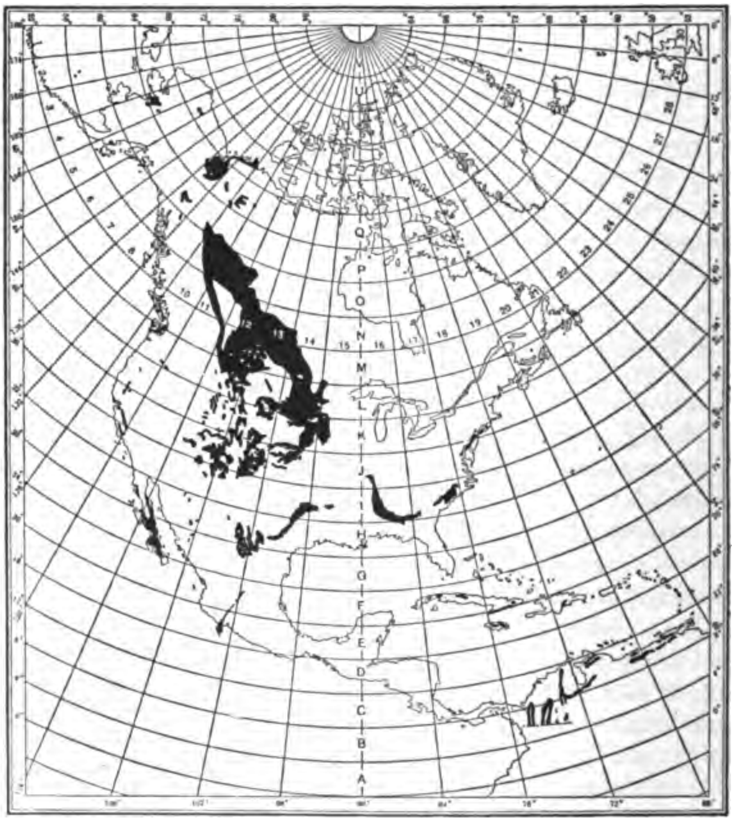


FIG. 1693. — Map showing the outcrops of the Cretaceous in North America. (After Bailey Willis.)

of the sea over an old land area. On Jamaica, which lies nearer the center of the east and west trough, the Cretaceous beds have an estimated thickness of 5000 feet, but they also begin with conglomerates formed of granitoid and metamorphic older (probably pre-Cambrian) rock. These conglomerates are succeeded by limestones with pelecypods of the type known as *Rudistes* (Fig.

1689), and by marls and calcareous sands with corals of southern European types. Much of the clastic material is of volcanic origin. On Porto Rico the Cretaceous succeeds the Comanchean (probably with a disconformity), and consists largely of clastic material, much of it of volcanic origin. Some beds abound in Foraminifera, and it is possible that they were deposited in open, though probably not very deep water, for *Rudistes* (*Radiolites*, etc., Fig. 1689 *f*, *g*) also occur, often in fragmentary condition.

It thus appears that deposits which now form the older and much folded series of these islands never originated very far from the oldland which formed the northern shore of the geosyncline, and that the center of this trough was somewhere near the middle of the present Caribbean Sea. Its southern margin overlapped northern South America, for Cretaceous beds are known from Colombia, Venezuela, and Trinidad, and while limestones with *Rudistes* are common, they are associated with sandstones and other clastic rocks. This geosyncline had a southward prolongation into the Andean trough (the present Andes Mountains) of Peru, and to some extent in Chile and Argentine, where the Cretaceous deposits are often underlain by Comanchean beds, showing that this trough also existed during the earlier period. They have, however, been little studied, but enough is known to warrant the belief that the trough was bounded, as in the preceding eras, by a land mass on the west (now submerged), and had little or no connection with the Pacific. Some of the Cretaceous beds of this trough are of continental character, and in several regions beds of lignite and brown coal of economic importance are found.

The fauna of these central waters was largely of a European type and is especially characterized by the extensive development of *Rudistes* (*Radiolites*, *Hippurites*, etc., Figs. 1723, 1724). These extend south into the Andean trough, where other pelecypods (*Exogyra*, etc., Figs. 1692, 1706) and ammonites of European origin are more frequent. The *Rudistes* and accompanying types also extend northward into the Coloradoan trough of Texas, but farther north the fauna seems to be primarily a northern one, so that it appears that temperature conditions largely determined the distribution of these organisms. So far as known the fauna did not enter the Neo-Appalachian geosyncline to any great extent, probably because of colder currents from the northeastern Atlantic opening of this geosyncline.

Where these Cretaceous strata are to-day exposed on the Rio Grande, they have a thickness of about 7500 feet with 1500 feet of white limestone or chalk (*Austin chalk*) in the lower part. Farther north the beds become thinner, and the limestones also decrease, so that their thickness at Austin, Texas, is only 600 feet and becomes less than a hundred feet in Colorado. This shows a northward transgression of the sea into this trough and an overlap of the marine strata in that direction. While the limestones were

FIG. 1694. — A cliff of Greenhorn limestone, the middle member of the Benton division of the Cretaceous. This limestone marks essentially the lowest horizon at which the pelecypod *Inoceramus labiatus* appears, this occurring here in great abundance, near Thatcher, Colorado. (U. S. G. S.)

forming in the open waters of the south, river-borne muds were accumulating in the north, these forming the *Benton shales*, which are chiefly of estuarine character but with marine limestones in the center (Fig. 1694). In many places the shales abound in fish remains, but other fossils are rare or absent. This suggests that the fish were either river types killed in large numbers by the advancing sea, or marine types killed by the inpouring fresh water. Their decaying bodies were probably in large part the source from which the petroleum now stored in porous members of this series was derived. Similar fish-bearing shales overlie the *Niobrara* limestone series. During the earlier part (Coloradoan) of the Cretaceous, when the muds of the north

FIG. 1695. — Coal-bearing sandstone of the Upper Cretaceous (Mesa Verde formation). Rock Springs Dome, Wyoming. (U. S. G. S.)

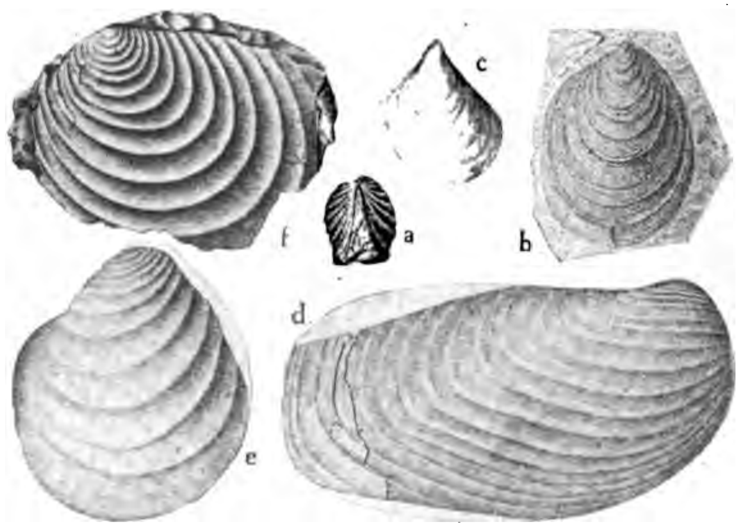


FIG. 1696. — Species of the most characteristic Cretaceous pelecypod, *Inoceramus*.

a, *I. dimidius* ($\times \frac{2}{3}$), Coloradoan of Kansas, Colorado, Utah, New Mexico; *b*, *I. labiatus* ($\times \frac{2}{3}$), typical of the Benton, throughout the Plains and Rocky Mountain region, lower Turonian of Europe; *c*, *I. fragilis* ($\times \frac{1}{3}$), Benton shale from Texas to Dakota; *d*, *I. simpsoni* ($\times \frac{1}{3}$), Coloradoan of Kansas and South Dakota, also Cretacic of San Louis Potosi, Mexico; *e*, *I. deformis* ($\times \frac{1}{3}$), Niobrara of the Plains and Rocky Mountains; *f*, *I. proximus* ($\times \frac{1}{2}$), Pierre of South Dakota and Colorado, Ripleyan of New Jersey and the Gulf region. (I. F.)

were mainly estuarine, the marine fauna from the south invaded this trough, the first immigrant being the pelecypod *Inoceramus labiatus* (Fig. 1696 *b*) (middle Benton), followed by ammonites (*Prionotropus*, *Prionocyclus*, Fig. 1697), and later by the coarse thick-shelled *Inoceramus deformis* (Fig. 1696 *e*), easily recognized by its coarsely prismatic shell-structure. In Montanan time, however, the Arctic sea transgressed into this trough from the north, bringing with it *Baculites* (Fig. 1698 *a–e*), *Scaphites* (Fig.

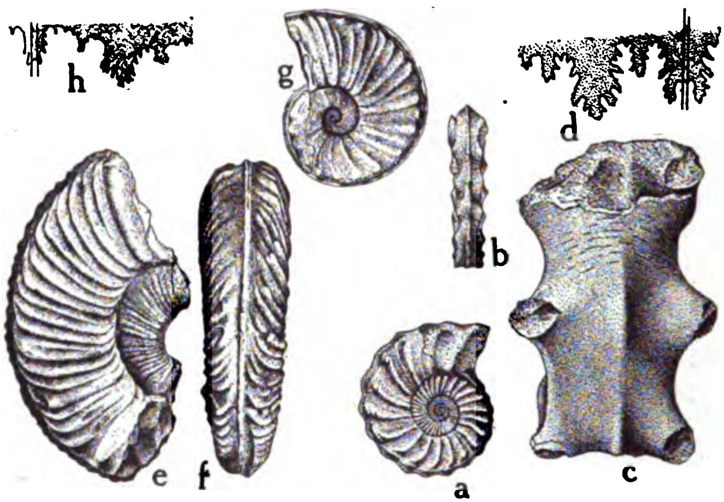


FIG. 1697. — Characteristic ammonites of the Lower Cretacic (lower Upper Cretaceous) or Coloradoan.

a–d, *Prionotropus woolgari*, Benton and equivalent beds from Texas to South Dakota, Turonian of Europe (*a*, *b*, two views of a young shell ($\times \frac{1}{2}$); *c*, fragment of a mature shell, ventral view ($\times \frac{1}{2}$); *d*, suture); *e–h*, *Prionocyclus wyomingensis*, upper Benton of northern Colorado geosyncline (*e*, *f*, two views of a fragment of an adult ($\times \frac{3}{4}$); *g*, a young shell ($\times \frac{3}{4}$); *h*, suture. (I. F.)

1698 *f–h*), *Helicoceras* (Fig. 1754), and other peculiar cephalopods which are also found on the west coast of Greenland.

The material deposited at this time in the region of the present Great Plains was largely mud, forming the thick *Ft. Pierre shales* (1000 feet). Some portions of these shales are characterized by pillar-like masses of limestone largely composed of the shells of a pelecypod (*Lucina*, Fig. 1699). These are regarded as representing colonies of the pelecypod, growing in circumscribed areas as do banks of mussels to-day, generation after generation living in the same spot and building up the column of shell-limestones

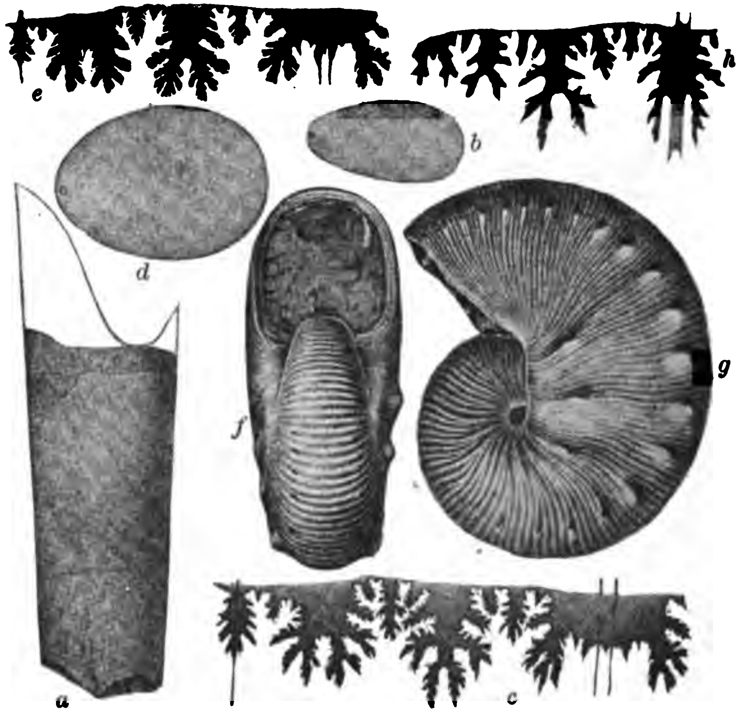


FIG. 1698. — Middle and Upper Cretaceous degenerate ammonoids, showing loss of power to coil.

a–c, *Baculites compressus*, side view and cross-section (× [illegible]) and suture (much enlarged), Pierre of the Coloradoan geosyncline, Ripleyan of New Jersey; *d*, *e*, *Baculites ovatus*, cross-section (× [illegible]) and suture (much enlarged), Pierre of the Coloradoan geosyncline, Ripleyan of New Jersey; *f*, *g*, *Scaphites nodosus* var. *brevis* (× [illegible]), Montanan of the Coloradoan geosyncline, Ripleyan of New Jersey; *h*, *S. nodosus* var. *quadrangularis*, suture enlarged, Montanan of Colorado geosyncline. (I. F.)

FIG. 1699. — *Lucina occidentalis*, a pelecypod abundant in the Pierre of Colorado and the region from Kansas to Canada, and in the Fox Hills of South Dakota. It grew in reef-like masses forming the Tepee-Buttes (see Figs. 1700–1702).

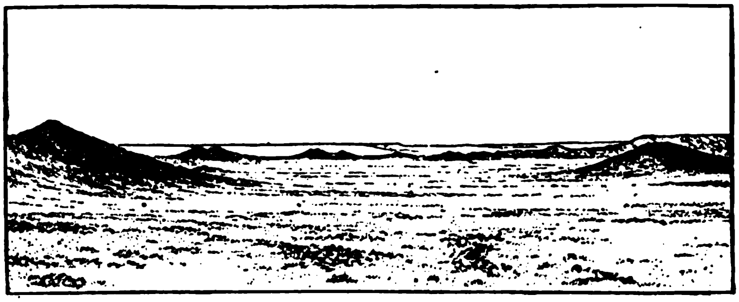


Fig. 1700. — General view of Tepee-Buttes in Upper Cretaceous (Pierre) strata near Canyon City, Colorado. (After Gilbert and Gulliver.)

as the older part was progressively buried in the accumulating mud. Subsequent erosion has produced a series of conical buttes with the shell-limestone as the resistant core (Figs. 1700–1702). The Pierre is succeeded by a sandstone, the *Fox Hills*, which is frequently cross-bedded and indicates progressive emergence of the region (Fig. 1703).

Fig. 1701. — A single Tepee-Butte, showing at the top the limestone core. (After Gilbert and Gulliver, from *Principles of Stratigraphy.*)

The western part of the Coloradoan trough was the site of extensive continental deposits, formed by rivers flowing from the old land on the west (map, Fig. 1704). These formed great flat plains, dotted over with swamps, in which accumulated an abundant vegetation which is now preserved in the many important coal

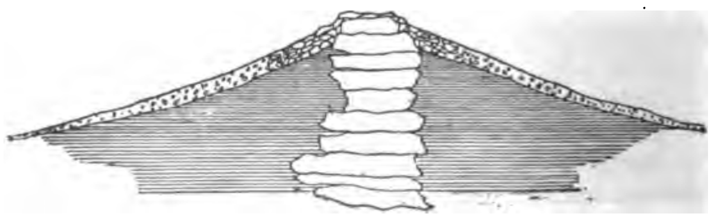


Fig. 1702. — Ideal section of a Tepee-Butte, showing the core of organic limestone, the surrounding bedded shales, and the talus-covered slopes. (After Gilbert and Gulliver, from *Principles of Stratigraphy.*)

beds of this region (Fig. 1695). The sea from the eastern portion of the trough inundated these flats repeatedly, so that deposits with marine fossils became intercalated in the continental series. In Canada extensive continental deposits, chiefly sand, were formed during the Cretaceous (*Bear River*, *Judith River* and other formations). In general all of these western coal-bearing deposits

FIG. 1703. — Upper Cretaceous (Fox Hills) sandstone, showing cross-bedding of the eolian type, Wyoming (F. J. Pack, photo.).

shade off eastward into equivalent marine beds, one series thinning as the other thickens. Finally, the marine beds were overspread, far and wide, by the continental *Laramie sands*, which mark the final retreat of the sea from this entire basin.

Cretaceous Beds of the Neo-Appalachian Trough

The Southern Region. — In western Alabama the Cretaceous beds are about 2400 feet thick and are subdivided as follows:

SUPERFORMATION. Eocene.

Hiatus and Disconformity

CRETACEOUS SERIES		*Approximate European equivalents*
Selma chalk	900 feet	Senonian
Eutaw formation *	400–500 feet	Emscherian
Tuscaloosan formation *	1000 feet	Turonian and Cenomanian

Hiatus and Unconformity

SUBFORMATION. Palæozoic.

* The upper part of the Eutaw ranges into the Senonian and the upper part of the Tuscaloosan into the Emscherian.

FIG. 1704. — Palæogeographic map of North America, showing the distribution of land and sea (black) in Cretaceous time. (Original.)

It will be observed that the highest Cretaceous deposits (Danian) are absent here; they were either never deposited, or, if deposited, have again been eroded. The Comanchean is absent too, the Cretaceous resting by overlap directly upon the eroded Palæozoic of the old Appalachian Mountains. This overlap continues northward and eastward, so that in Tennessee and in eastern Alabama the Eutaw rests directly upon the older rocks, as shown in the following diagram (Fig. 1705).

The *Tuscaloosa* is a shore or delta formation, and is probably in large part a subaërial accumulation. The sands are often glauconitic, and the clays not uncommonly carbonaceous and lignitic, with an abundance of fossil plants. The *Eutaw*, on the

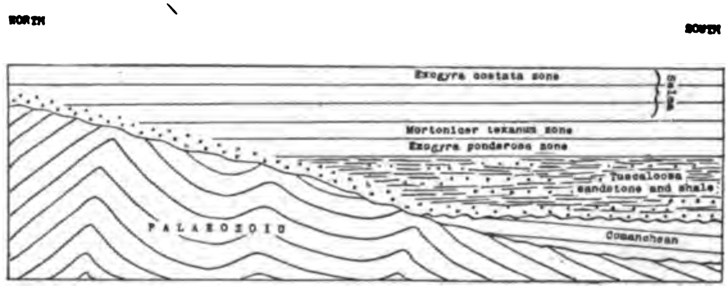


FIG. 1705. — Ideal section of the Gulf Coast region of the southern United States, showing the relationships and overlaps of the Cretaceous formations. (Original.)

other hand, is largely a marine formation, showing the advance of the sea over the Tuscaloosa delta. Plant remains also occur at two horizons, and the marine fossils are chiefly thick-shelled pelecypods, indicating shallow water. The progressive advance of the sea is shown by the fact that toward the northwest and the east this formation, too, is overlapped by the next higher, the *Selma chalk*. This is an argillaceous, more or less sandy limestone, abounding in Foraminifera and carrying beds made up largely of the thick-shelled pelecypod *Exogyra* (Figs. 1706 *a–c*). The presence in it of the rudistid pelecypod *Radiolites austinensis* shows that the fauna of the Texas and southern waters entered this geosyncline to some extent at least. Eastward this formation is more and more replaced by calcareous sands, clays, and impure limestones, which constitute the Ripley formation, while northwestward much sand also appears.

There are several important zone fossils which mark the horizon throughout this region, irrespective of change in lithic character. The upper part of the Eutaw (*Tombigbee sand*) is characterized by the large and heavy *Exogyra ponderosa* (Fig. 1706 *c*), which

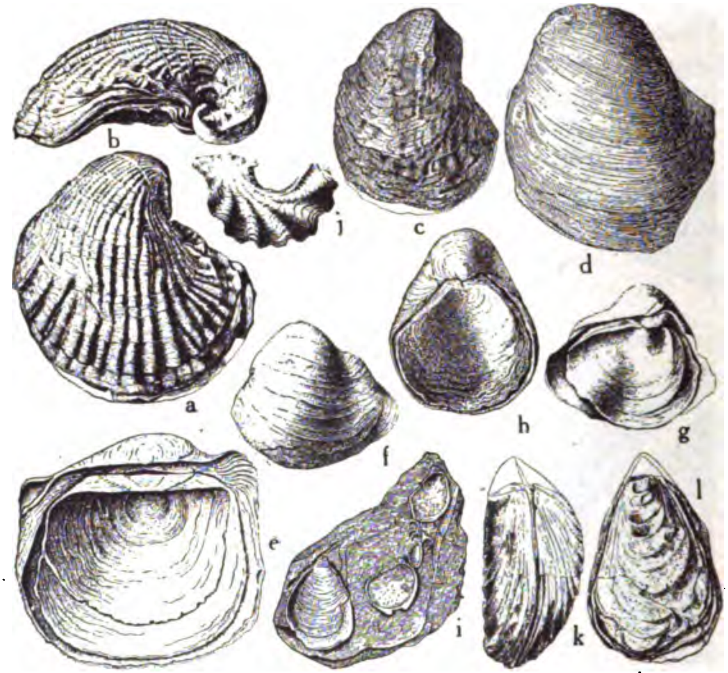


FIG. 1706. — Cretaceous (Cretacic) and Upper Comanchean oysters and related pelecypods.

a, b, Exogyra costata, two views of lower valve (× ½), upper divisions of the Atlantic region; *c, Exogyra ponderosa*; lower valve (× ½), Ripleyan of Atlantic region, Coloradoan of Utah, Texas, and Mexico; *d, Gryphæa vesicularis* (× ½), Upper Comanchean (Washita) of Mexico, Cretaceous of Atlantic and Coloradoan geosynclines, Europe; *e, Gryphæa mutabilis*, both valves in conjunction, Upper Cretaceous of Atlantic region; *f, g, Gryphæa convexa*, opposite views (× ½), Cretaceous of Atlantic region; *h, Gryphæa newberryi* (× ½), Coloradoan of the Colorado geosyncline; *i, Ostrea congesta* (× ½) attached to a fragment of shell of *Inoceramus deformis*, Coloradoan (Niobrara) of Colorado geosyncline; *j, Ostrea falcata* (*O. larva*) (× ½), Upper Cretaceous of Atlantic region; *k, l, Ostrea glabra*, side and top views (× ½), Upper Cretaceous (Pierre to Laramie) of Coloradoan geosyncline. (I. F.)

appears here for the first time, and is typical of this zone. It is the subzone of the ammonite *Mortoniceras* (of the *M. texanum* type, Fig. 1707 *c, d*). The higher part of the Selma forms the zone of *Exogyra costata* (Fig. 1706 *a, b*), readily distinguished from the lower species by its pronounced plications. Among the 185 species of this zone the coarse and large *Gryphæa vesicularis* (Fig. 1706 *d*), the small plicated oyster, *Ostrea larva* (Fig. 1706 *j*), and the belemnite *Belemnitella americana* (Fig. 1707 *e–h*) may be noted. This last

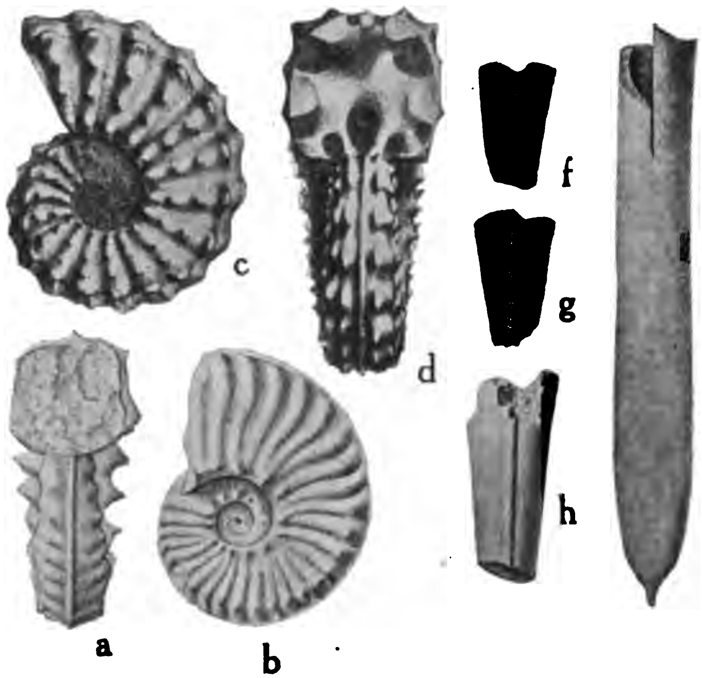


FIG. 1707. — Comanchean and Cretaceous cephalopods of the Atlantic geosyncline.

a, b, Schloenbachia leonensis ($\times \frac{1}{3}$) Comanchean (lower Washita) of Texas; *c, d, Mortoniceras texanum* ($\times \frac{1}{3}$) Cretaceous (Austin and Selma chalk of Gulf region); *e–h, Belemnitella americana* ($\times \frac{2}{3}$), (*e*, guard; *f, g*, two views of phragmocone; *h*, view of the filling of the cavity (alveolus) in which the phragmocone rests. When the latter is destroyed the cavity is often filled with mud which on hardening produces a cast of the phragmocone). Cretacic of New Jersey and the southeastern and southern United States. (I. F.)

species appeared in North Europe in the Mæstrichtian (upper Senonian) and thus serves for approximate correlation.

The Northern Region. — If we now consider the exposures at the northern end of the trough in New Jersey, we find the series only about 800 feet thick and less than half that in Maryland, for only the thin shore ends of the formations of the trough are here exposed. They comprise the following divisions:

SUPERFORMATION. Palæocene (Shark River formation).

CRETACEOUS		
Manasquan formation	50 feet	Danian
Rancocas formation	125 feet	
Monmouth group	150 feet	Mæstrichtian
Matawan group	275–400 feet	Campanian Santonian
Magothy formation	100 feet	Emscherian
Hiatus and Disconformity		

SUBFORMATION. Raritan formation.

Here it will be seen that the series begins with higher members than it does farther south (Emscherian as compared with Cenomanian), showing that the older beds are overlapped. But in this section the continental Raritan (Dakota), and Comanchean beds are present. Here we find also the highest Cretaceous division, the *Danian*, which is followed, apparently with conformity, by the lowest Tertiary beds. The *Monmouth* is the equivalent of the upper part of the Selma, being characterized by *Belemnitella americana* (Fig. 1707 *e–h*) and *Exogyra costata* (Fig. 1706 *a*, *b*). The *Matawan* carries the *Mortoniceras* zone in its lower part and therefore corresponds to the top of the Eutaw and to the European Santonian, near the base of which this fossil occurs. Thus the Cretaceous beds of New Jersey represent only the Senonian (comprehensive sense inclusive of Emscherian) and the Danian; that is, only the upper part of the European Upper Cretaceous. The fauna of these beds is most nearly like that of the northwest European Senonian, which would indicate that if these American beds were deposited in a geosyncline this opened to the Atlantic on the northeast.

The Comanchean and Cretaceous Deposits of the West Coast Geosyncline

The west coast geosyncline, located mainly in California, Oregon, and the Canadian region to the north, was entirely separated from the interior region and had faunas wholly peculiar to itself though of types also found on the west Pacific (Asiatic) border. Both Comanchean and Cretaceous beds are found here and the two appear to represent continuous deposition in a transgressing sea. These deposits are divided (in northwest California) as follows:

CRETACEOUS or CHICO SERIES	3,897 feet
Massive and thin-bedded sandstones with conglomerates.	
COMANCHEAN or SHASTA SERIES	
Horsetown beds	6,109 feet
Sandstones, often thin-bedded, and shales. (Upper part transitional to Cretaceous.)	
Knoxville beds	19,974 feet
Shales with calcareous layers in the upper 10,000 feet, interbedded with sandstones below.	
Total Comanchean and Cretaceous	29,980 feet

This enormous thickness of nearly six miles of strata, all of which represent shallow-water deposits, indicates a progressive subsidence of this geosyncline, until when the last of the beds were deposited

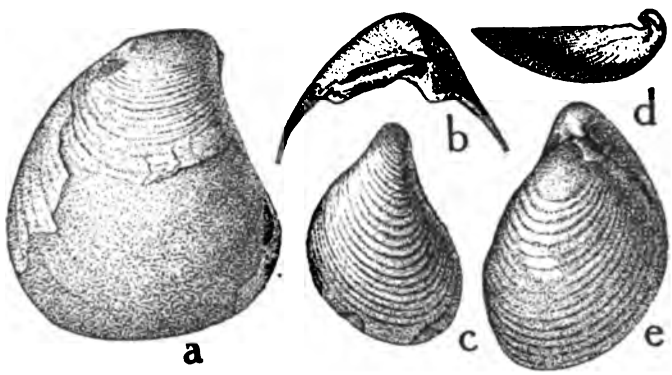


FIG. 1708. — Comanchean species of *Aucella*, a characteristic boreal pelecypod of the Pacific geosyncline. *a*, *b*, *Aucella crassicollis* (a right valve; *b*, hinge of the left valve); *c*, *d*, *A. piochii* (left valve, two views); *e*, variety *ovata*, both valves in conjunction. (I. F.) All ×1.

at sea-level, the first lay at a depth nearly equal to the greatest oceanic depths known to-day. This also implies an enormous amount of erosion of the bounding lands on either side of the geosyncline. During this subsidence the sea transgressed over the shores of earlier time, so that the various members of this great series overlap one another. Such overlaps are well shown in a number of sections.

The *Knoxville* beds are especially characterized by the pelecypod *Aucella piochii* (Fig. 1708 *c*, *d*) in the lower, and *A. crassicollis* (Fig. 1708 *a*, *b*) in the upper 2000 feet, and the ammonites *Phylloceras*, *Olcostephanus*, and *Hoplites* (Fig. 1742). The *Horsetown* is without *Aucella*, but the ammonites continue upwards, though represented by different species, while loose coiling forms (*Crioceras*, Fig. 1748, etc.) also occur. In the higher beds occurs *Schloenbachia inflata* (Fig. 1749) also found in the European Gault. This genus of ammonites is also well represented in the Chico by other species. Most of the fossils of this horizon, as of the upper Horsetown, are related to those of India and the west Pacific, while the Knoxville fauna is a boreal one.

On Queen Charlotte Island these beds contain both coal and iron ore, the former showing that continental conditions of accumulation existed here. On Vancouver only the Cretaceous (Chico) beds occur, these overlapping the Shasta series, although the latter is found to the east. This shows that in Comanchean (Shasta) time Vancouver was a part of the land mass bounding the geosyncline on the west. These western Cretaceous beds can be traced northward into Alaska, where they are also often coal-bearing.

The Cretaceous of Europe

Lower Cretaceous

On the opening of Lower Cretaceous (Neocomian) time, much of the area submerged during Jurassic time had again been uncovered by the late Jurassic retreat, when continental sediments formed over a wide area. So much of Europe had been uncovered that regions where the late marine Jurassic is immediately succeeded by early marine Cretaceous are found only in a few localities, especially in the Mediterranean basin (Alpine region) and central Russia. Such a continuous series of marine deposits has also been thought to exist in eastern England (Speeton clay), but it seems more probable that there, too, a hiatus exists between the Jurassic and Lower Cretaceous.

The Lower Cretaceous of Europe was characterized by continental deposition or by erosion over the emerged areas and by a slow transgression of the sea from the persistent marine centers (Mediterranean, Central Russia, etc.) over the land, successive members of the series thus coming to rest by overlap either upon the eroded land surfaces or upon the continental deposits.

The Continental Deposits.—These are best known from southern England, where they are exposed in the center of the great eroded anticlinorium of the Weald. From their occurrence there these deposits are called the Wealden formation, and they are essentially similar in character and in age to the American Morrison formation. The Wealden was largely formed by rivers, the principal one of which probably came from the west or southwest along a line somewhat to the west of the present English Channel,[1] while others came from a more northwesterly direction (Fig. 1709). It consists of sands at the base, followed by clays, and the whole is several thousand feet thick in its maximum development, thinning away, as such deposits always do, in a more or less radial manner from the head

FIG. 1709. — View at Tunbridge Wells, England, showing the Upper Tunbridge Wells sand capped by Wealden clay. (Miss M. C. Crossfield, photo.)

of the fan except where it was banked against cliffs which existed at that time. These deposits enclose remains of plants and fresh-water shells (*Unio*, *Paludina*, etc., *ante*, pp. 51, 52) and the bones of dinosaurs. In one case (Isle of Wight) a raft of coniferous trees is enclosed in the Wealden clay, similar to rafts found in the sands and clays of some modern rivers, and the entire deposit may perhaps be compared with the Indo-Gangetic plain of northern India or the great flood-plain of the Yellow River of China. (See *ante*, p. 467, Pt. I). Similar river deposits were forming in north-eastern Spain (northern Aragon and Old Castile), where this old flood-plain covers an area of more than 3000 square kilometers and reaches a maximum thickness of 1000 meters (map, Fig. 1714).

[1] From manuscript by M. O'Connell.

Deposits of this type also accumulated in northern Germany and Poland, but these were largely derived from the old Vindelician land mass of central Europe which still existed and had even become enlarged. In these deposits thin coal seams are sometimes found.

The Marine Series. — In Lower Cretaceous time Europe was divided by the Vindelician land mass and its eastward continuation into a northern or boreal marine basin, centering in Russia, and a southern or Mediterranean basin which included the Balearic basin and which was apparently in communication with the Atlantic across southern Spain (map, Fig. 1714). These Mediterranean waters were characterized by a fauna in which peculiar thick-shelled pelecypods (*Requienia*, Fig. 1710; *Monopleura*, Fig. 1711) predominated, types which, as we have seen, are also found in the Gulf deposits of the American Comanchean, which was in continuous connection across the Atlantic with the Mediterranean. These organisms frequently occurred in enormous numbers, forming, together with calcareous algæ and Foraminifera, reef-like structures. Such reefs are now recognizable in the Lower Cretaceous series of southern Europe as white, pure, and structureless masses of limestone embedded in more normally stratified limestones of the same age. On account of their massive character the later erosion has left them as peaks and ridges, while solution has honeycombed them with grottos and caves.

FIG. 1710. — *Requienia ammonia* (×½), a Lower Cretaceous, southern European rudistid.

As the Mediterranean waters advanced northward, the successive members of the Lower Cretaceous series overlapped one another in that direction. Thus the Berriasian and Valanginian are found only in southeastern France, the Hauterivian which overlies these extends to Burgundy, Champagne, and the Loire region, while the Barremian next above extends into northern France where the Aptian also occurs. This relationship is dia-

FIG. 1711. — *Monopleura trilobita* (slightly reduced), a Lower Cretaceous, southern European pelecypod.

grammatically represented in Fig. 1712. The north Spanish delta was covered by the sea in Albian time, for marine deposits of this age are the first to rest upon the continental beds except where these are not present (northwest Teruel), when the marine Albian rests

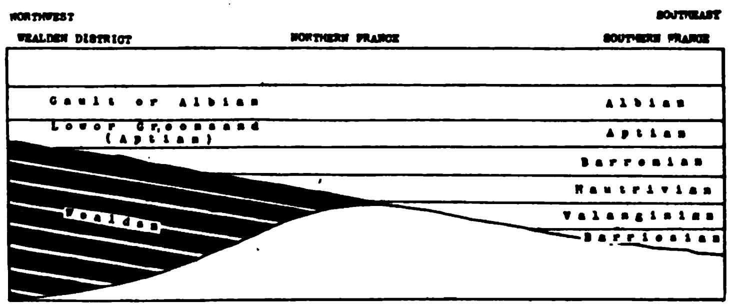


FIG. 1712. — Ideal section from southeastern England to southern France, showing the overlaps of the Lower and Upper Cretaceous beds (Comanchic and Cretacic), on the Wealden and the old basement rocks. Vertical scale greatly exaggerated. (Original.)

directly and disconformably upon the eroded Jurassic. The southeastern portion of the Castilian delta in Catalonia, however, was covered earlier by the transgressing sea, for there Barremian marine beds rest upon the continental deposits (Fig. 1713). The

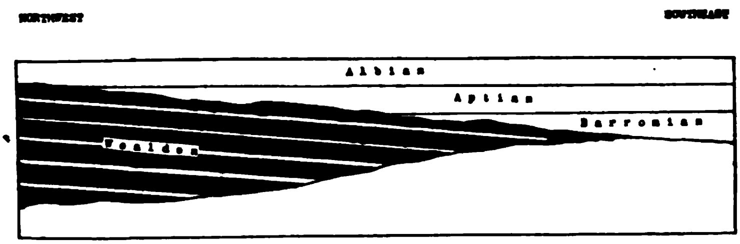


FIG. 1713. — Ideal section showing the overlaps of the Cretaceous (Comanchic and Cretacic) beds upon the Castilian alluvial fan (Wealden type) of northeastern Spain. Note that Barremian, Aptian and Albian rest successively on Wealden. (Original.) Compare with English Wealden, Fig. 1712.

Wealden delta of England was covered in Aptian time by the Lower Greensands, which are followed by the Albian or Gault clays. This transgression extended beyond the area of the Wealden deposits, and in some parts of England these later Lower

Cretaceous marine beds rest directly upon the eroded surface of the Jurassic.

About this time the southern sea became confluent across northern France and southeastern England with the northern sea which had transgressed from Russia across northern Germany to eastern England (Figs. 1714, 1715).[1] Phosphate deposits are commonly found near the base of the series. Into this sea sands were washed from the Vindelician highland on the south, while clays accumulated

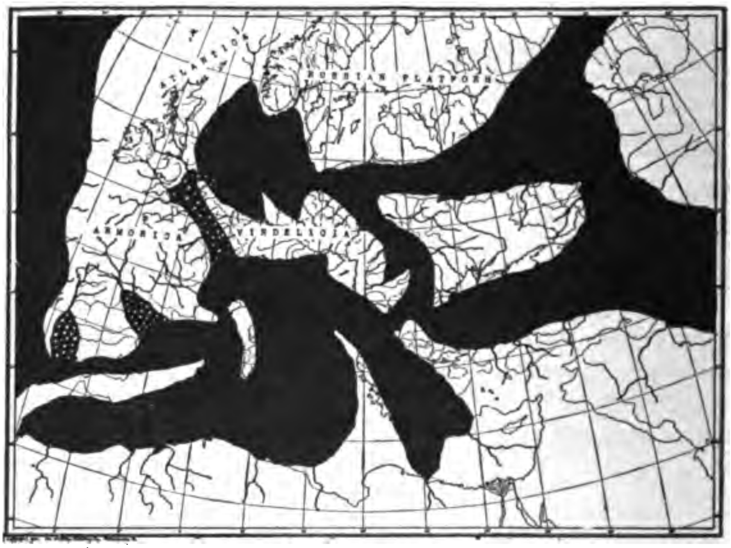


FIG. 1714. — Palæogeographic map of Europe showing the distribution of land and water (black) in Barremian time. (Modified after Haug and others.)

away from the shores of that sea. The fauna of this basin is distinct from that of the Mediterranean, and occurs throughout the deposits in eastern England, northern Germany, Poland, and central and far northern Russia. It is a boreal fauna, with *Aucella* and ammonites similar to some of the west American types.

[1] It must be remembered that some authorities hold that the sea never wholly retreated from this region, — they believe that the Speeton clays of eastern England represent continuous marine conditions from late Jurassic through Lower Cretaceous time. They also hold that these deposits were formed in an arm of the Arctic Sea which extended southward along the present North Sea Channel, parallel to another arm of this sea in Russia west of the Urals, and that no direct connection existed across north Germany. Further investigation is required before these palæogeographic conditions can be fully determined.

The great retreatal movement of the sea which occurred at the end of Comanchean time in North America is not indicated in western Europe, but seems to have taken place in northern Russia and northern Asia.

The Upper Cretaceous (Cretacic) of Europe

It is possible that the close of the Lower Cretaceous was marked by a more extensive shoaling and retreat of the sea than is now recognized in Europe, where certain formations (*e.g.* Gault clay)

FIG. 1715. — Palæogeographic map of Europe, showing the distribution of land and water (black) in lower Aptian time. (Modified after Kilian and others.)

at this horizon may represent the combined deposits of a retreating followed by an advancing sea, as does the Dakota sandstone in America. In any case, with the opening of the Cretaceous in Cenomanian time Europe suffered a widespread transgression of the sea, and many regions not flooded during the preceding period were now slowly submerged. This brought with it an overlap of the successive formations shown in the following diagram of the Cretaceous deposits of Great Britain (Fig. 1717). This, too, shows the progressive migration of the facies, so that the succession in the kinds of rock in the two end sections is essentially the same, but each one of the beds in Ireland begins at a higher horizon. Thus the basal conglomerate and sand zone is of Aptian age in southeastern England, but of Cenomanian age in Ireland.

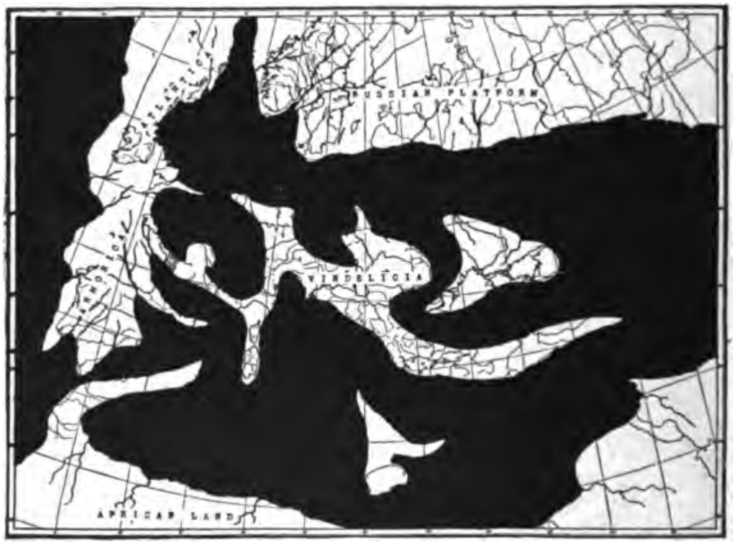


FIG. 1716. — Palæogeographic map of Europe showing the probable distribution of land and water (black) in Cenomanian time. (Modified after Haug and others.)

The next zone of glauconite sands and marls is of Albian age in southeastern England but of Turonian age in Ireland. Again the zone of marls and glauconite and argillaceous chalk is of Cenomanian age in southeastern England, but of lower Senonian in

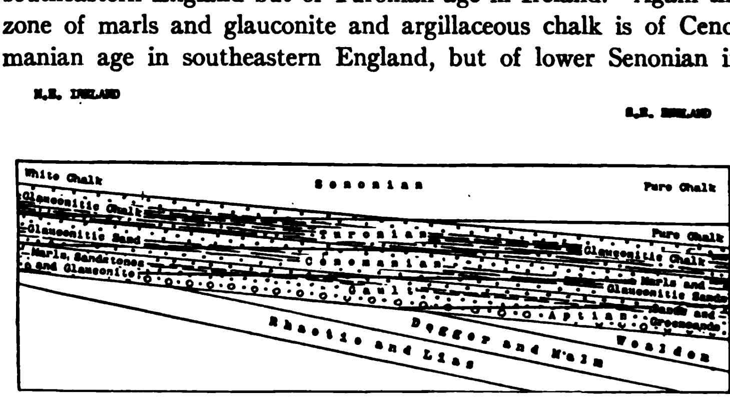


FIG. 1717. — Ideal section from southeastern England to northeastern Ireland, showing the overlaps of the Cretaceous strata and their change in facies. (Original.)

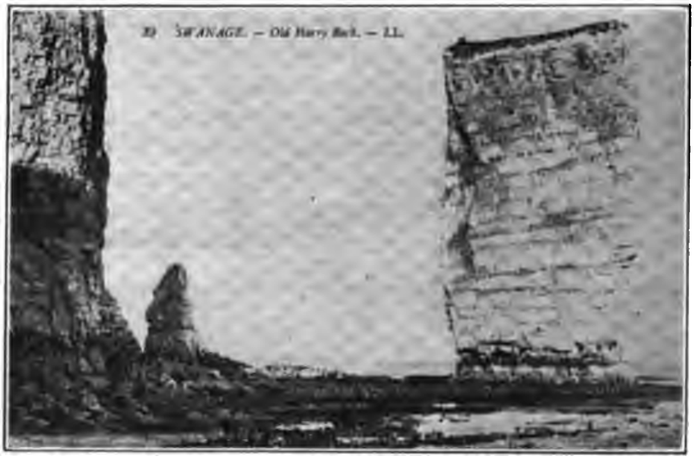


FIG. 1718. — Chalk cliffs of the south coast of England, showing the stratified character of the Chalk, and the vertical cliffs due to jointing and to vigorous wave attack at the base. View from Peverel Point, Swanage.

northeastern Ireland. Finally, the White Chalk begins in the Turonian in England but not until the upper Senonian in Ireland.

The chalk is one of the most characteristic deposits of the Cretaceous of northwestern Europe, and has given its name to the

FIG. 1719. — Chalk cliffs between Mers and the Ault (Somme), France. (After Haug.)

formation. It is to-day seen in the cliffs of the English and French Channel coasts (Figs. 201, p. 279, 713, p. 807, Pt. I; Figs. 1718, 1719), and in many inland and North Sea coast sections (Fig. 1720), but its modern distribution covers only a small part of its former extent. It is not impossible that the greater part of England, including Wales, was at one time covered by this formation. Chalk, as has already been explained (p. 278, Pt. I), is the product of the accumulations of vast numbers of minute foraminiferal shells, of

FIG. 1720. — Cliff of Cretaceous strata on the coast of Norfolk, England. At the base is the Lower Greensand followed by the Hunstanton Red Rock (red chalk), while the main part of the cliff is formed of the white chalk. (From Lake and Rastall.)

fragments of the same and of the calcareous plates called coccoliths, etc. (probably of algous origin). The chief organisms of the chalk are of types which to-day live in shallow water, and this fact and the remarkable overlap relations outlined above clearly indicate that these beds were laid down in a comparatively shallow transgressing sea, and not in abyssal depths as is the case with the best known modern foraminiferal deposit, the *Globigerina* ooze (*ante*, p. 275, Pt. I). The fact that the White Chalk is practically without terrigenous material indicates that the shores of the land over which the sea was transgressing were so low that they did not furnish material of this type. Mingled with the calcareous matter, however, were the silicious spicules of sponges and probably to some extent radiolarian shells as well. These silicious particles have since been dissolved by waters circu-

FIG. 1721. — Massive cross-bedded sandstone of the Cretaceous (Quader-sandstein). Altvater hills, Germany. (After Walther.)

lating through the chalk and the silica has been redeposited at certain levels in the form of bands of flint nodules. At various horizons in the Chalk series layers are found which contain the shells of pelecypods, the tests of sea-urchins, and other organisms, but the

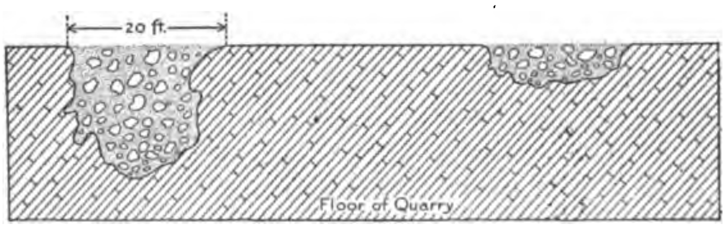


FIG. 1722. — Section in a quarry at Kahlebusch near Dresden, Saxony, showing the nature of the contact between the Cretaceous and the crystallines. The old rock is a basic porphyry peneplaned but with scattered pothole-like hollows which are filled with sand and worn boulders of the porphyry. The walls are smooth but irregular and Cretaceous oysters are attached to them in places. Among the boulders occur Cenomanian sponges and other organisms. (From the author's field notes — published by M. O'Connell, Am. Mus. Nat. Hist. Bull.)

Fig. 1723. — *Hippurites toucasiana*, large valve with two buds. (After d'Orbigny.)

bulk of the Chalk consists only of minute shells or of clastic lime particles.

The Cenomanian transgression of the sea is everywhere marked in Europe by the overlap of this or the succeeding divisions, so that they rest directly upon the older rocks, even upon the crystallines (Bohemian border). In many cases extensive deposits of sand characterized the lower divisions of the Cretaceous, this being especially so in the Bohemian region and the adjoining district of Germany (Quader sandstone). Such are the sandstones from which the picturesque erosion monuments along the River Elbe south of Dresden are carved which have given this region the name of the "Saxon Switzerland" (Figs. 341 *a*, *b*, p. 408, Pt. I, Fig. 736, p. 5). This sandstone sometimes shows cross-bedding of the torrential type (Fig. 1721). In the region now occupied by the Carpathian Mountains, great deposits of sands (*Flysch formation*) formed in shallow water along the border of the mid-European continent, and in some sections of north Europe sand was the dominant type of deposit during Cretaceous time, limestones forming only a subordinate part of the whole. Frequently the series begins with coarse boulder conglomerates which rest directly upon the old crystalline rocks (vicinity of Dresden, Bohemia, etc.) or in erosion hollows in these (Fig. 1722). It is a remarkable fact that these boulder masses often enclose well-preserved brachiopods and oyster shells, as well as sponges, many of which appear to have lived among the boulders on the old sea-bottom. The limestones contain chiefly oysters, sponges, and other shallow-water organisms.

Fig. 1724.—*Hippurites cornu-vaccinum*. Upper Cretaceous, southern Europe.

Throughout Cretaceous time the Mid-European (Vindelician) land mass divided Europe into a northern and a southern marine

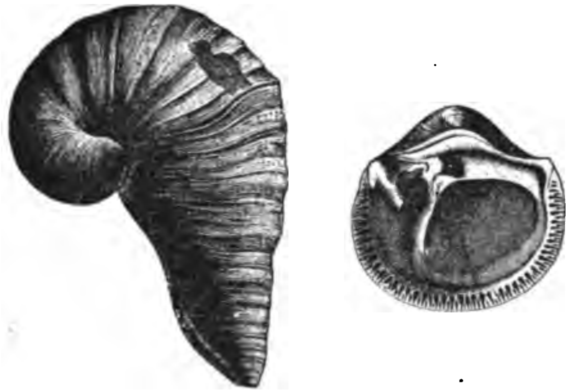


FIG. 1725. — *Caprina aiguilloni* side view and interior of smaller valve. (After d'Orbigny.)

basin, the latter (Tethys), occupying the region of the modern Mediterranean, extended, however, beyond its present shores while the northern basin covered much of Russia, Poland, Germany, the north of France, Belgium, the Netherlands, and England. It

FIG. 1726. — Section showing the interfingering of the Turonian Hippurite limestone (heavy-bedded layers at top) with the torrential, cross-bedded conglomerate of the same age. At the debouchure of the Rhone, France. (After Haug.)

was in this northern sea that the chalk accumulated and, in Senonian time at least, a connection with the Atlantic seems to have existed, for the northern Senonian fauna of Europe is also found in the Atlantic coast deposits of North America.

FIG. 1727.—Gorge of the Gosau River in southern Germany in the northern limestone Alps. This is a typical locality for the Gosau beds of Cretaceous age.

The Southern, or Mediterranean, Sea, on the other hand, was the site of great limestone accumulations, which were often largely composed of the coarse rudistid and related shells, especially of the genera *Hippurites* (Figs. 1723, 1724), *Radiolites*, and *Caprina* (Fig. 1725). These *Rudistes* are sometimes found intercalated between torrential river deposits of the same age, showing that they lived in shallow water, near to the shore of the time (Fig. 1726). The fact that some of these forms are found in the Cretaceous deposits of the West Indies and elsewhere in the American Gulf region embayment shows that transoceanic migration was possible between Europe and America. Another northern shore facies of this sea, consisting largely of shales and marls, is typically exposed in the Gosau gorge of the Eastern Alps (Fig. 1727).

In the southeastern part of the Tethys sea (Egypt) the Cretaceous begins with a sandstone, which rests transgressively upon the older

FIG. 1728. — Nubian sandstone resting on decomposed igneous rock, Second Cataract of the Nile, Soudan.

rocks and rises in age southward, *i.e.* in the direction of sea transgression. This is the *Nubian sandstone* (Fig. 1728), from the disintegration of which the sands of the Libyan desert are largely derived.

CHARACTERISTIC ORGANIC REMAINS

Marine Invertebrates. — **Foraminifera** are abundant in both Comanchean and Cretaceous rocks, especially, as we have seen, in the chalk. As they are of microscopic dimensions, they are not usually recognized except in thin sections. In the chalk the commonest forms are *Textularia* (Fig. 1729 *a*) and *Rotalia* (Fig. 1729 *b*), but numerous other forms occur. **Sponges** are very abundant

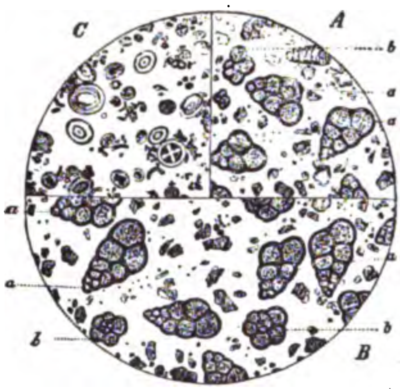


FIG. 1729. — Section of chalk showing characteristic fossils. *a*, *Textularia*, *b*, *Rotalia*.

FIG. 1730. — *Jereica polystoma*, part of spicular skeleton of a silicious sponge of the Cretaceous.

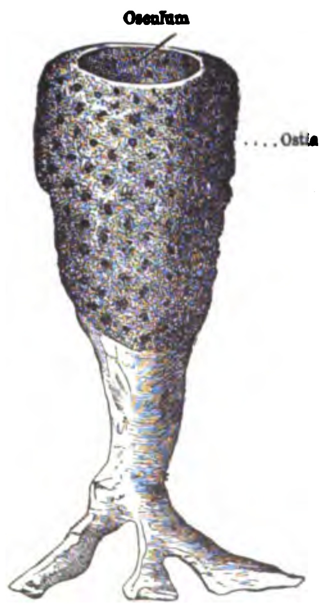


FIG. 1731. — *Ventriculites simplex*. A silicious sponge of the Cretaceous.

FIG. 1732. — *Coscinopora infundibuliformis* (slightly reduced). Upper Cretaceous (Senonian) silicious sponge.

FIG. 1733. — *Cœloptychium agaricoides* (× ½), an Upper Cretaceous (Senonian) silicious sponge.

in the European Cretaceous, but they are difficult fossils to determine. Most characteristic are the pear-shaped, long or short stemmed genera, *Siphonia*, *Jereica* (Fig. 1730), etc., and especially the striking beaker-shaped *Ventriculites* (Fig. 1731) and *Coscinopora* (Fig. 1732), and the mushroom-shaped *Cœloptychium*

FIG. 1734. — *Actinostromaria stellata* (×½). Cenomanian stromatoporoid. Île Madame (Charente-Inférieure, France). (After Haug.)

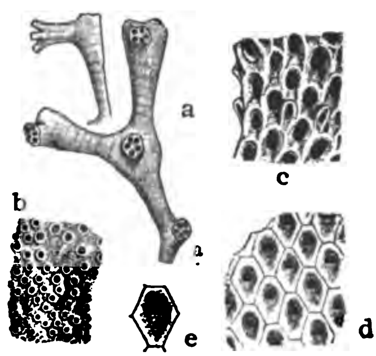


FIG. 1735. — Cretaceous Bryozoa. *a*, *Filifascigera megæra*, top and side views (×9); *b*, *Discosparsa varians*, enlargement of surface (×6); *c*, *Biflustra torta*, surface (×10); *d*, *e*, *Onychocella digitata*, surface (×10); and single zoœcium (×15). All Upper Cretaceous of Atlantic province. (I. F.)

(Fig. 1733). Sponges are not common in the American Cretaceous. What appears to be the last of the **Stromatoporoids**, occurs in the Cenomanian of Europe (Fig. 1734). **Corals** are seldom abundant and not very characteristic,

FIG. 1736. — *Rhynchonella vespertilio*, Upper Cretaceous of Europe.

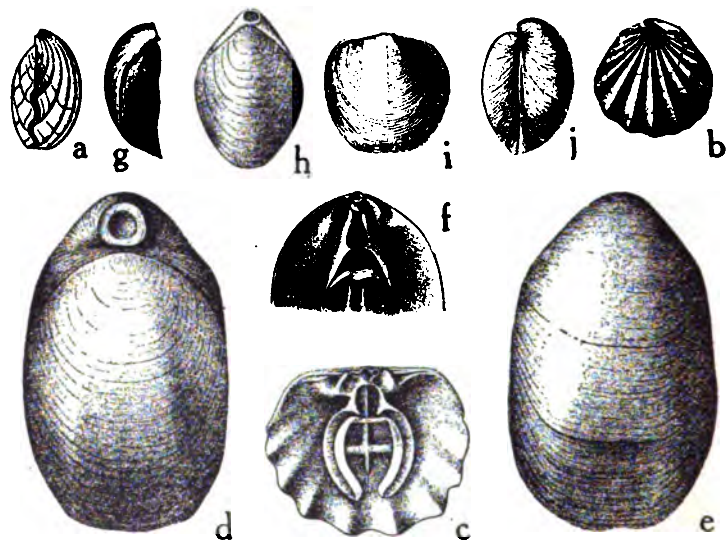


FIG. 1737. — Comanchean and Cretaceous Brachiopoda.

a–c, Terebratella plicata; Upper Cretaceous Atlantic province (*a*, side view, *b*, dorsal view (× [illegible]), *c*, interior of brachial valve enlarged); *d–f, Terebratula harlani* (× [illegible]), opposite views and interior of brachial valve showing loop, Upper Cretaceous Atlantic Coast; *g–h, Terebratulina atlantica* (× [illegible]), Upper Cretaceous Atlantic Coast province; *i–j, Kingena wacoensis*, front and side views, Washita of Texas and Vancouver. (I. F.)

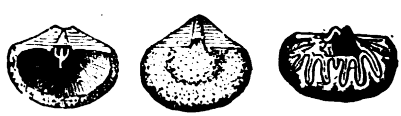


FIG. 1738. — *Thecidium digitatum*, an Upper Cretaceous European brachiopod. Interiors of opposite valves and entire shell in center.

but **Bryozoa** abound in many sections, especially the order Chilostomata (Fig. 1735). They require, however, careful microscopic study for their determination. **Brachiopods** are not common except locally where the rhynchonelloid and terebratuloid types predominate (Figs. 1736–1738). Very char-

FIG. 1739. — *Pecten asper* (slightly reduced). The characteristic pelecypod of the lowest beds (Cenomanian) of the Cretaceous of Europe.

aeteristic, however, are the **pelecypods**, especially the oysters, including *Gryphæa* and *Exogyra*, of which the smaller and more strongly curved abound in the Comanchean and the larger coarser forms in the Cretaceous (see Figs. 1692, 1706, and 1740–1741). *Aucella* (Fig. 1708) is characteristic of the boreal Coman-

FIG. 1740. — *Inoceramus brongniarti* (× ½), Cretaceous (Turonian) of Europe.

FIG. 1741. — *Inoceramus cuvieri* (× ⅓). Cretaceous (Turonian) of Europe.

chean and *Inoceramus* (Figs. 1696 *a–f*) of the Cretaceous as a whole. Some of these shells may grow to a length of several feet and are important limestone makers. Most striking, however, are the rudistid pelecypods characteristic of the Mediterranean and Gulf Cretaceous, *Requienia* (Fig. 1710) and

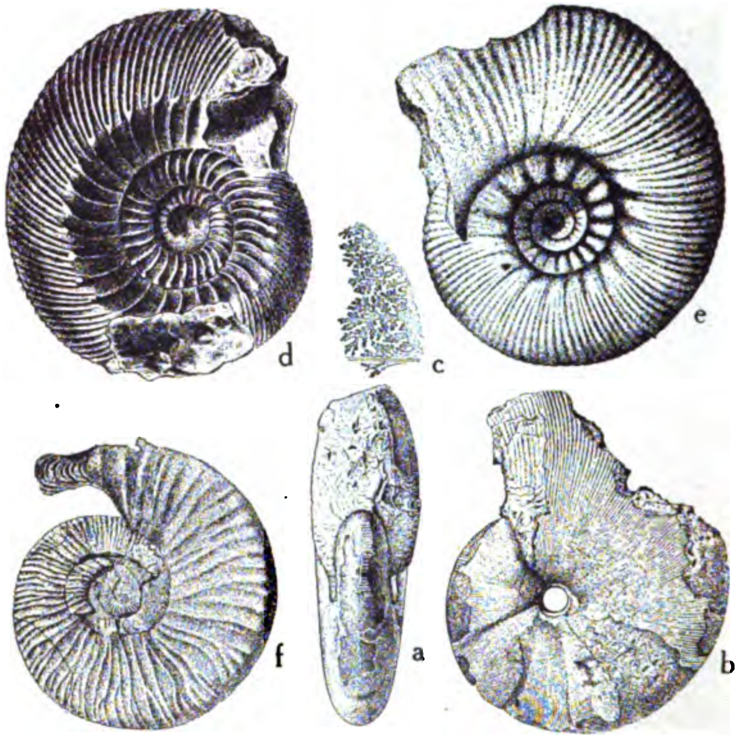


FIG. 1742. — Comanchean ammonites of the Pacific geosyncline.

a–c, ***Phylloceras knoxvillense***, two views ($\times \frac{2}{3}$), and suture, Knoxville; *d*, ***Olcostephanus loganianus*** ($\times \frac{2}{3}$), Queen Charlotte; *e*, ***O. traski*** ($\times \frac{2}{3}$), Horsetown; *f*, ***Lyticoceras hyatti*** ($\times \frac{2}{3}$), Knoxville. (I. F.)

FIG. 1743. — ***Olcostephanus astierianus.*** Comanchean (Hauterivian) of Europe.

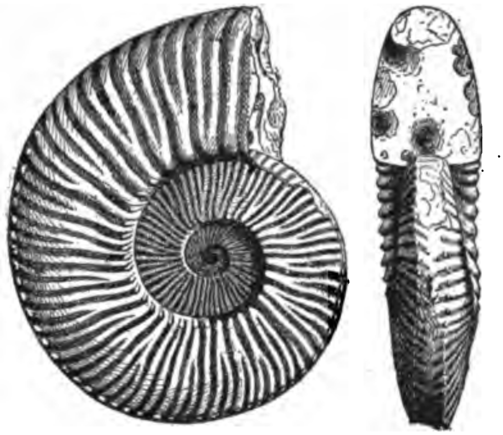


FIG. 1744. — *Hoplites noricus*, Comanchean (Hauterivian) of Europe.

Monopleura (Fig. 1711) predominating in the Comanchean (Lower Cretaceous), and *Hippurites* (Figs. 1723–1724), and *Caprina* (Fig. 1725) in the Cretaceous.

Gastropods though locally abundant are less significant as index fossils. **Ammonites** are still abundant, but they are chiefly represented by highly ornamented forms (ribbed, fluted, noded, or spinose), or by types which in the adults have partly or entirely lost the power of coiling. Among the Lower Cretaceous types may especially be mentioned *Phylloceras* (Fig. 1742 *a–c*), *Olcostephanus*

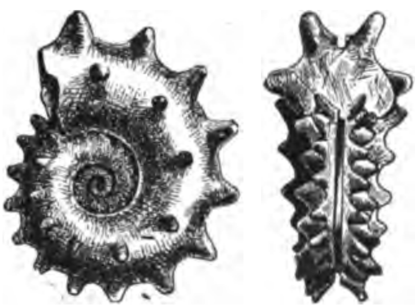


FIG. 1745. — *Hoplites tuberculatus* (Gault) of Europe.

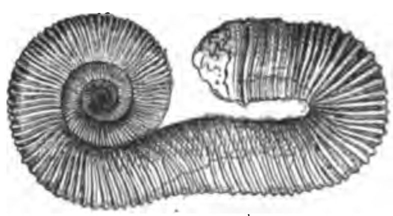


FIG. 1746. — *Macroscaphites ivani*, Comanchean of Europe. The adult stage shows a non-coiling character with terminal recurvature.

FIG. 1747. — *Crioceras emerici*, Comanchean of Europe. This is a loose-coiling spinous form.

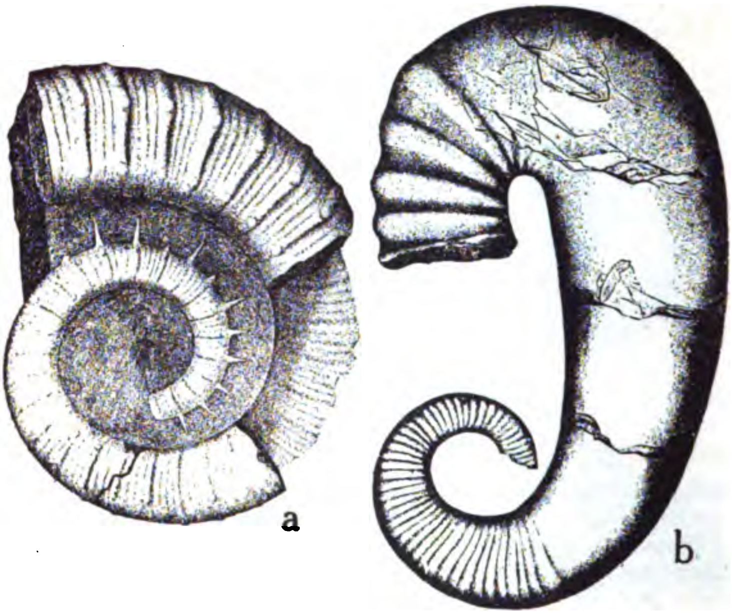


FIG. 1748. — Loose-coiling (degenerate) ammonites of the Comanchean of the Pacific geosyncline. *a*, *Crioceras latum* (×⅓), Knoxville; *b*, *Ancyloceras percostatum* (×⅓), Knoxville and Horsetown.

FIG. 1749. — *Schloenbachia inflata* (×½), a Lower Cretaceous (Gault) ammonite of Europe. Horsetown of western North America.

(Fig. 1742 *d*, *e*, 1743), and the less ornamented *Hoplites* (Fig. 1744), and further the genera *Crioceras* recognized by the loose coils (Fig. 1747, 1748), and *Macroscaphites* (Fig. 1746). Characteristic Upper Cretaceous genera are: *Schloenbachia* (Figs. 1707 *a*, *b*, 1749, 1750), highly ornamental species of *Hoplites* (Fig. 1745), *Douvilleiceras* (Fig. 1751), *Mortoniceras* (Fig. 1707 *c*, *d*), *Acanthoceras* (Fig. 1752), and *Scaphites* (Fig. 1698 *f–h*), with the last whorl curved

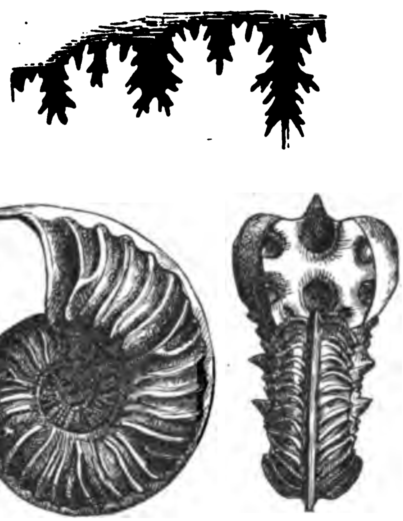


FIG. 1750. — *Schloenbachia cristata*, two views and suture (Gault), of Europe (France, etc.). (After d'Orbigny.)

at a greater spiral. Other forms are the irregularly coiled or twisted *Hamites* (Fig. 1754 *a*), *Heteroceras* (Fig. 1754 *e–g*), *Ptychoceras* (Fig. 1754 *h–j*), etc., and *Baculites* (Fig. 1698 *a–e*), a straight form, except for the tiny apical coil. Large, laterally flattened, close-coiled, and mostly smooth ammonites with the suture highly complex (*Placenticeras*, Fig. 1755), or of ceratitic character, by retarda-

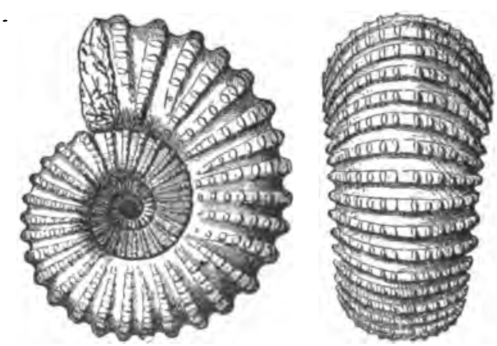


FIG. 1751. — *Douvilleiceras mammillare*, Comanchean (Gault) of Europe.

tion (*Sphenodiscus*, *Engonoceras*, etc., Figs. 1756 *e–j*) also occur in the higher Cretaceous. The **belemnites** are still well represented, especially by the flattened or grooved *Duvalia* (Fig. 1757) in the Lower, and the mucronately pointed *Belemnitella* (Figs. 1707 *e–h*, 1758) in the Upper Cretaceous. **Nautiloids** are wholly represented by the *Nautilus* group of close-coiled shells (Fig. 1760).

FIG. 1752. — *Acanthoceras rotomagense* (×$\frac{2}{3}$), Cretaceous (Cenomanian) of Europe.

FIG. 1753. — *Turrilites catenatus*, bottom and side views. (After d'Orbigny.) (This type coils after the manner of a left-handed gastropod.)

Many of these still have simple *Nautilus* sutures, but at the very close of the period a form with an undulating suture arose (*Hercoglossa danica*, Fig. 1761). Among the **Crustacea** decapods (crabs, etc., Fig. 1762) are most frequently represented, though Ostracods and other classes are not uncommon.

Among the **echinoderms**, the echinoids or sea-urchins are the principal index fossils. They comprise mostly the irregular forms which show distinct bilateral

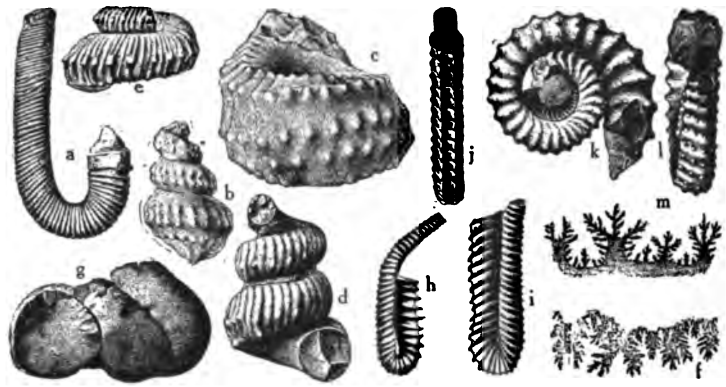


FIG. 1754. — Comanchean and Cretaceous ammonoids, which show old-age characteristics, especially in the loss of the power of coiling. These characteristics appeared in many unrelated genera, indicating that the race as a whole was on the decline. All ammonites became extinct at the end of the epoch.

a, *Hamites obstrictus*, Lower Cretacic (Coloradoan) of the Vancouver Islands group ($\times \frac{3}{4}$); *b*, *c*, *Turrilites brazoënsis* ($\times \frac{3}{4}$), (*b*, apical whorls, loosely coiled like a gastropod; *c*, portion of an adult whorl), Comanchic (Washita) of Texas; *d*, *Helicoceras stevensoni* ($\times \frac{3}{4}$) (the final whorl of this form usually straightens out like *Hamites*), Cretacic (Pierre) of the Black Hills; *e*, *f*, *Heteroceras* (*Didymoceras*) *newtoni*, fragment ($\times \frac{3}{4}$) and suture ($\times \frac{3}{4}$), Cretacic (Pierre) of the Black Hills; *g*, *Heteroceras* (*Didymòceras*) *tortum* ($\times \frac{3}{4}$), Cretacic (Pierre) of the Black Hills; *h*, *Ptychoceras meekanum* ($\times \frac{3}{4}$), and *i*, *j*, *Ptychoceras* (*Oxybeloceras*) *crassum* ($\times \frac{3}{4}$), forms similar to *Hamites* but having the whorls in contact, Cretacic (Pierre) of the Black Hills; *k–m*, *He'icancyclus æquicostatus*, top and side views of spiral of a small individual ($\times \frac{3}{4}$), and suture much enlarged, Cretacic (Chico) of California.

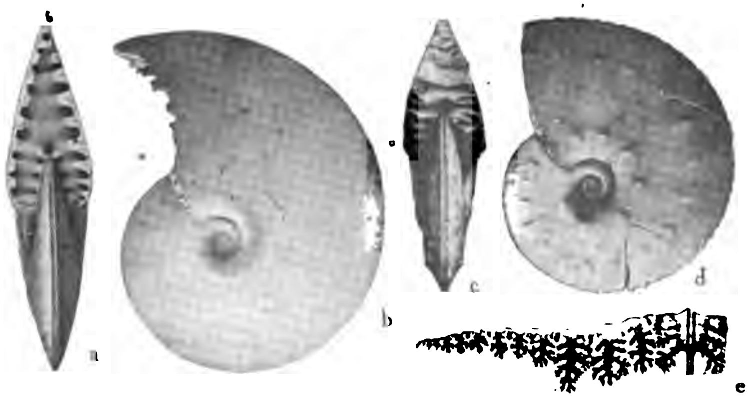


FIG. 1755. — Cretaceous (Montanan) ammonites.

a, *b*, *Placenticeras whitfieldi* ($\times \frac{1}{3}$), front and lateral views, Cretacic (Pierre) of Nebraska, South Dakota, and Colorado; *c–e*, *Placenticeras intercalare*, front and lateral views ($\times \frac{1}{2}$), and suture enlarged, Cretacic (Pierre) of Black Hills. (I. F.)

symmetry; a number of these are illustrated in Figures 1763–1765. Two crinoids also were common in the Cretaceous beds of certain localities, both without stems and apparently of a floating habitat. These were the European *Marsupites* (Fig. 1766) and the American *Uintacrinus* (Figs. 1767, 1768) which sometimes covers huge slabs of rock in enormous numbers.

Fresh-water Invertebrates. — These comprise genera of Mollusca still living, such as the fresh-water mussel, *Unio* (Fig. 1769 *p–t*), and the snails *Viviparus*

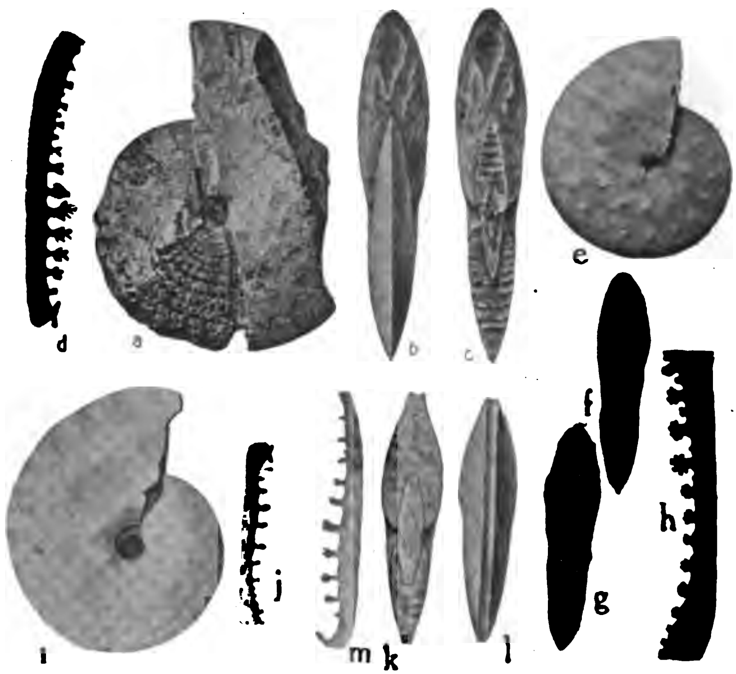


FIG. 1756. — **Retarded ammonites with ceratitc sutures (pseudoceratites), from the Comanchean and Cretaceous.**

a–d, ***Metengoceras dumblii*** (× ½), a flat, lens-shaped form with angular venter and simple leaf-like sutures, Coloradoan of Texas; *e–h*, ***Sphenodiscus pleurisepta*** (× ⅓), Coloradoan of Texas and Mississippi; *i, j*, ***Engonoceras pierdenale*** (× ⅓), Comanchic (Fredericksburg of Texas); *k–m*, ***Protengonoceras gabbi*** (× ⅓), with the venter marked by two ridges forming a keel, Comanchic (Fredericksburg) of Mexico. (I. F.)

(Fig. 1769 *i–j*), *Planorbis* (Fig. 1769 *m–o*), etc. The minute bivalved ostracod crustacean *Cypridea* (Fig. 1780) is also characteristic of many fresh-water deposits of the Cretaceous.

Land Plants and Insects. — In the terrestrial deposits of the Comanchean (Morrison, Wealden, etc.) cycads, conifers, and ferns were the principal types, the higher angiospermous plants still being wanting. The higher plants appear rather abruptly towards the close of the Lower Cretaceous (Dakota of America, Gault of Europe) and possess almost from the beginning an astonishing likeness to modern types. Here we find representatives of the beech, oak, tulip tree, maple, magnolia, sassafras, willow, eucalyptus (now confined to tropical

FIG. 1757. — *Belemnites (Duvalia) dilatatus*, Comanchean of southern Europe.

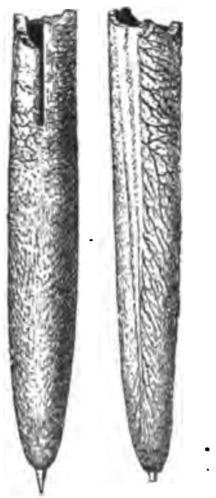


FIG. 1758. — *Belemnitella mucronata* (× ⅔), Upper Cretaceous (Senonian) of Europe.

FIG. 1759. — *Actinocamax quadrata* (slightly reduced), Upper Cretaceous (Senonian) of Europe.

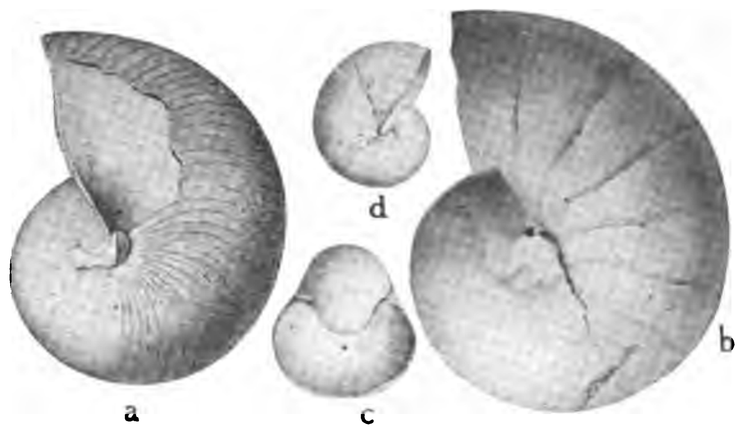


FIG. 1760. — Cretaceous nautiloid cephalopods. *a*, *Cymatoceras elegans* (× ½), Benton of Missouri and Texas; *b-d*, *Nautilus (Eutrephoceras) dekayi* (× ½); (*b*, large specimen of variety *mortonense*; *c*, *d*, two views of a small (young) individual). Ripleyan of the eastern and southeastern United States, Montanan of Texas, Nebraska, Montana, and Canada. (I. F.)

regions), and many others. Some of these are illustrated in Figures 1773 *a–i*. Palms too were widely distributed at this time. With this rise in the flora there is also an abrupt increase in the insect world, many modern types making their first appearance.

Vertebrates. — These include fish, especially the modern bony types (teleosts, which first became abundant in the seas of Upper Cretaceous time),

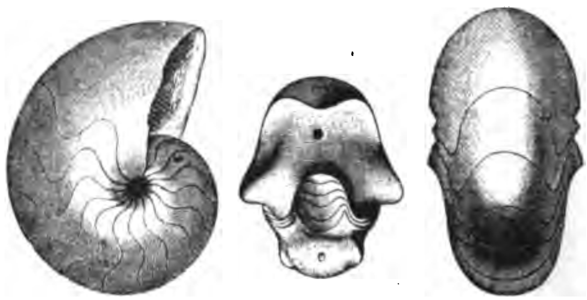


FIG. 1761. — *Nautilus (Hercoglossa) danicus*, a characteristic fossil of the highest Cretaceous strata (Danian) in Europe, North Africa, etc. Side and ventral views of shell and fragment, showing the character of the septa, and the siphuncle. (After D'Orbigny.)

amphibians, and reptiles. The last of the aquatic saurians (ichthyosaurs and plesiosaurs) occur there as well as the last of the pterosaurs or flying saurians (*Pteranodon* with a wing-spread of 6 meters, Figs. 1811–1813). During Cretaceous time the last of the dinosaurs walked the earth. The Comanchean dinosaur fauna included creatures of gigantic dimensions, such as the huge

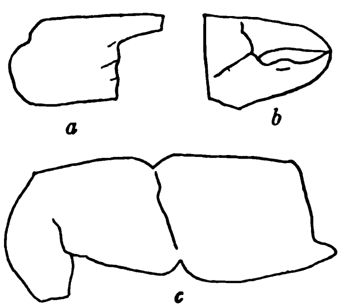


FIG. 1762. — Outlines of fragments of crab-claws (*a, Callianassa conradi; b, c, C. mortoni*) (×⅞); Cretaceous of the Atlantic province. (I. F.)

Brontosaurus (Fig. 1797) and *Diplodocus* (Fig. 1794), and the Cretaceous, the grotesquely horned *Triceratops* (Fig. 1806). Birds, still with toothed jaws, occur (*Hesperornis*, Fig. 1815; *Ichthyornis*, Fig. 1817), and many small though primitive mammals are found. These various groups of animals will be more fully discussed in the next chapter.

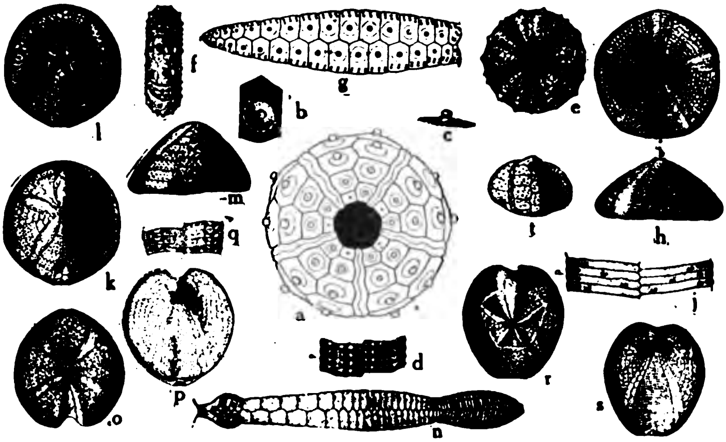


FIG. 1763. — Comanchean and Cretaceous echinoids of North America.

a–d, *Cidaris texana* ($\times \frac{3}{4}$) (*a*, test restored; *b*, interambulacral plate enlarged; *c*, tubercle much enlarged; *d*, portion of ambulacral area enlarged), Comanchic (Washita) of Texas; *e–g*, *Diadema* (*Pseudodiadema*) *texanum* ($\times \frac{3}{4}$) (*e*, upper surface; *f*, side view; *g*, ambulacral area enlarged), Comanchic (Fredericksburg) of Texas; *h–j*, *Holectypus planatus* ($\times \frac{3}{4}$) (*h*, posterior view; *i*, lower surface; *j*, ambulacral plates much enlarged), Comanchic (Fredericksburg and Washita) of Texas; *k–n*, *Echinobrissus texanus* ($\times \frac{3}{4}$) (*k*, upper view; *l*, lower view; *m*, lateral view; *n*, enlargement of right postero-lateral ambulacrum), Cretacic (Niobrara) of Texas; *o–q*, *Cardiaster cinctus* ($\times \frac{3}{4}$) (*o*, dorsal view; *p*, ventral view; *q*, enlargement of ambulacral plate), Cretacic of New Jersey; *r*, *s*, *Hemiaster texanus* ($\times \frac{3}{4}$) (*r*, dorsal view; *s*, ventral view), Cretacic (Niobrara) of Texas; *t*, *Hemiaster parastatus* ($\times \frac{3}{4}$), lateral view, Cretacic (Ripleyan of Alabama and Mississippi; Jerseyan of New Jersey). (I. F.)

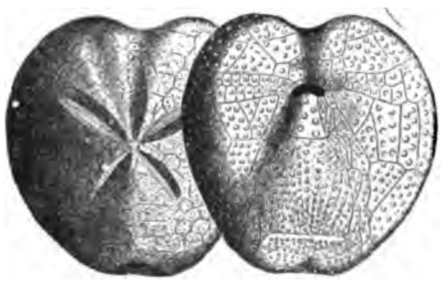


FIG. 1764. — *Micraster cor-testudinarium* ($\times \frac{3}{4}$), Upper Cretaceous (Senonian) of Europe. (K.)

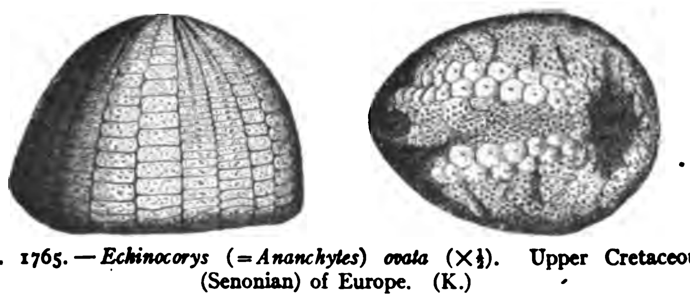


FIG. 1765. — *Echinocorys* (= *Ananchytes*) *ovata* ($\times \frac{1}{2}$). Upper Cretaceous (Senonian) of Europe. (K.)

Volcanism and Orogenic Disturbances

The Cretaceous was, on the whole, remarkably free from volcanism except towards its close, when extensive volcanic outbursts occurred in western North America, in India, and elsewhere. Accompanying these, or following them, were great mountain-making disturbances, but these appear to fall mostly into the earliest Tertiary, the Palæocene, and they will be considered in that connection (Chapter XLV).

Fig. 1766. — *Marsupiles testudinarius* ($\times \frac{4}{5}$). A floating crinoid of the Cretaceous (Senonian), Europe. (K.)

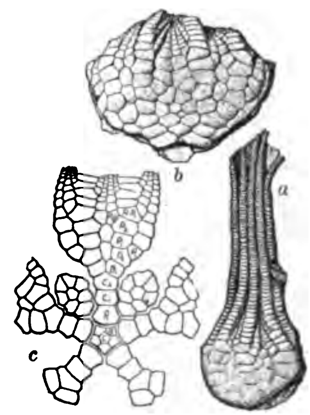


Fig. 1767. — *Uintacrinus socialis* ($\times \frac{1}{3}$). A floating crinoid of the Cretaceous (Niobrara).

a, small individual with arms partly preserved; *b*, lateral view of a larger calyx; *c*, analysis of the calyx: *C*, centrodorsal plate; *B*, basals; *R*, radials; C_1, C_2, costals; D_1, D_2, distichals; P_1, P_2, palmars; PP_1, post palmar. (I. F.)

Fig. 1768. — *Uintacrinus socialis*, photograph of a slab of shaly limestone showing numerous stranded individuals. (Reduced.)

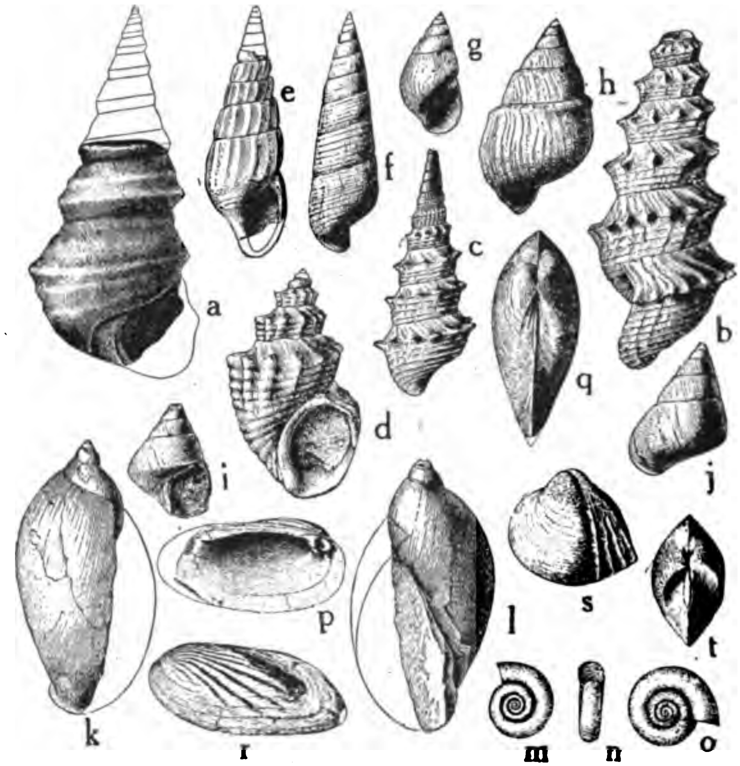


FIG. 1769. — Cretaceous brackish and fresh-water mollusks.

a, *Glauconia coalvillensis* ($\times \frac{1}{2}$), Coloradoan of Utah; *b*, *c*, *Melania wyomingensis* ($\times \frac{3}{4}$), Laramie beds of Wyoming and Colorado; *d*, *Pyrgulifera humerosa* ($\times \frac{3}{4}$), Bear River formation of Wyoming and Utah; *e*, *Goniobasis cleburni* ($\times \frac{3}{4}$), Bear River formation of Wyoming and Utah; *f*, *Goniobasis convexa* ($\times \frac{3}{4}$), Laramie beds, Wyoming; *g*, *Goniobasis nebrascensis* ($\times \frac{3}{4}$), Laramie of Yellowstone River region, Canada, Colorado, Utah; *h*, *Campeloma multilineatum*, Laramie beds of the upper Missouri region, and of the Bow and Belly regions of Canada; *i*, *j*, *Viviparus conradi*, Judith River formation of Wyoming, Montana, and Bow River region, Canada; *k*, *l*, *Physa copii* ($\times \frac{3}{4}$), Judith River beds of Montana and Canada; *m–o*, *Planorbis convolutus* ($\times \frac{3}{4}$), Judith River beds of the upper Missouri region; *p*, *q*, *Unio vetustus* ($\times \frac{5}{8}$), Bear River formation, Utah, Wyoming, Idaho; *r*, *Unio belliplicatus* ($\times \frac{5}{8}$), Bear River beds of Wyoming, etc.; *s*, *t*, *Unio holmesianus* ($\times \frac{5}{8}$), Laramie beds of Wyoming and Utah. (I. F.)

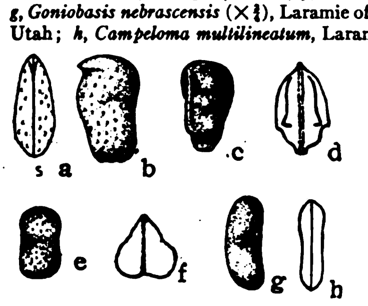


FIG. 1770. — Fresh-water ostracods of the Cretaceous (Bear River); *a*, *b*, *Cypridea wyomingensis* ($\times 14$); *c*, *d*, *Cythere monticulata* ($\times 20$); *e*, *f*, *Metacypris consobrina* ($\times 20$); *g*, *h*, *Cytherideis impressa* ($\times 20$). (I. F.)

CHAPTER XLIV

PROGRESS OF LIFE DURING THE MESOZOIC

THE most striking characteristic of the life of the Mesozoic is its almost complete distinctness from that of the preceding Palæozoic age, while to a lesser extent it differs from that of the succeeding Cenozoic. To be sure, there are certain classes of Mesozoic organisms which had their beginnings in the late Palæozoic, such as the ammonites, the amphibians, and even the reptiles, and indeed there can be no question that the Mesozoic types are all descendants from Palæozoic ancestors. Nevertheless, the differentiation was so complete that the contrast between the organisms of the two ages as a whole is most startling. This may have been due to rapid evolution at the close of the Palæozoic when, because of the great physical changes which had taken place, most of the older forms of life became extinct, thus making room for the development of new forms under the influence of the new physical conditions. We shall briefly note the principal groups.[1]

PLANTS

The Mesozoic flora readily falls into two strongly contrasted groups, that of the older Mesozoic to the top of the Comanchean and that of the Cretaceous. The older flora is primarily one of gymnosperms, the cycads and conifers predominating, while of the cryptogamic group ferns and equisetums form the principal representatives. By the beginning of the Triassic the dominant Palæozoic types had largely disappeared. The lepidodendrids, sigillarids, calamites, cordaites, sphenophyllæ, and cycadofilices had apparently all died out, together with some important genera of ferns. There is, however, one very notable survival from the late Palæozoic, and that is *Glossopteris*, which with some of its

[1] For classification and general characters of plants and animals, see Chapter XXVII.

associates has been found in Rhætic rocks of South Africa, New South Wales, and elsewhere.

Some of the ferns of the Triassic were of arboreal types, while equisetums with a diameter of four to five inches occurred. Some of the conifer trunks were 8 feet in diameter and belonged to trees at least 120 feet high. They showed, however, a complete or nearly complete absence of rings, from which it is inferred that the seasonal changes at that time were slight.

In the Jurassic there is a persistence of the dominant Triassic type, the cycads greatly increasing in number and kinds, while at the same time a number of new types appear (Figs. 1771–1772; see also Figs. 815, 816, pp. 84, 85). The Jurassic flora is remarkably uniform the world over. Not far from 50 per cent of the North American flora, exclusive of the cycad trunks, is the same as that found in Japan, Manchuria, Siberia, Spitzbergen, Scandinavia, and England, "and what is even more remarkable, the plants found in Louis Philippe Land, lat. 63° S., are practically the same as those from Yorkshire, England" (Knowlton). Besides the cycads, the Ginkgo or Maiden-hair tree (Fig. 817, p. 85) was extremely common in Jurassic time and widely distributed. To-day there is only a single species extant, a native of China and Japan, though introduced into the western world by man.

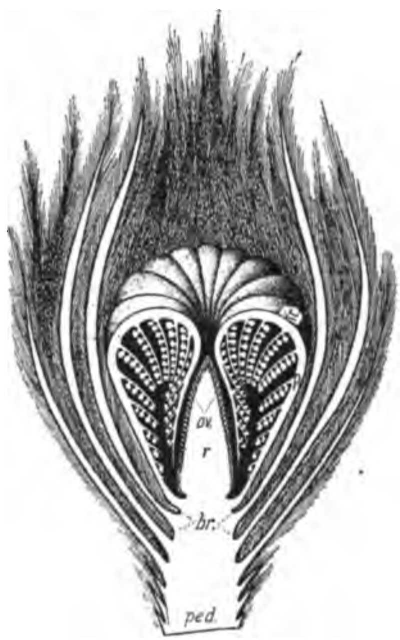


FIG. 1771.—Restoration of the flower bud of one of the extinct cycads (*Cycadeoidea dacotensis*) from the Upper Jurassic of South Dakota.

fr, folded staminate fronds with reduced pinnules (*p*) bearing closely crowded pollen sacs (the small white bulbs); *r*, the receptacle of the pistillate portion of the flower, covered marginally with the minute ovules (*ov*); *br*, bracts; *ped.*, pedicle or stalk. (After Wieland.)

This flora continues with little change into the Comanchean, ferns, and conifers, and cycads, ginkgos, and equisetiæ still making up the bulk of the flora, though new types have appeared.

Toward the close of the Comanchean, however, came the introduction of the true flowering or angiospermous plants, an event which has been called in many respects the most important and far-reaching biological one that the world has known (Knowlton). Remnants of this flora are first found in the Patapsco division of the Potomac group of the Atlantic coast Comanchean, but it is already so well developed that there must evidently have been a considerable time interval antedating the period in which these

FIG. 1772. — Typical and common conifers of the Upper Jurassic of Solnhofen, Germany. *a*, *Brachyphyllum* (*Echinostrobus*) *stombergi*; *b*, *Palæocyparis* (*Athrotaxites*) *princeps*. (After Berry.)

deposits were formed and during which the development of this flora took place. Where the flora originated cannot at present be stated. Once introduced, however, it quickly became modified into a wealth of types, and spread with surprising rapidity, so that it soon became the dominant flora. In the Dakota sandstone alone, over five hundred species occur (Fig. 1773 *a–f*), but comparatively few forms are known from the Coloradoan, largely because of the widespread marine character of the formations of this division. The flora of the Middle Cretaceous (Montanan) is not especially distinct from that of the Dakota, but in the Upper Cretaceous (the Laramian) occurs a flora very dis-

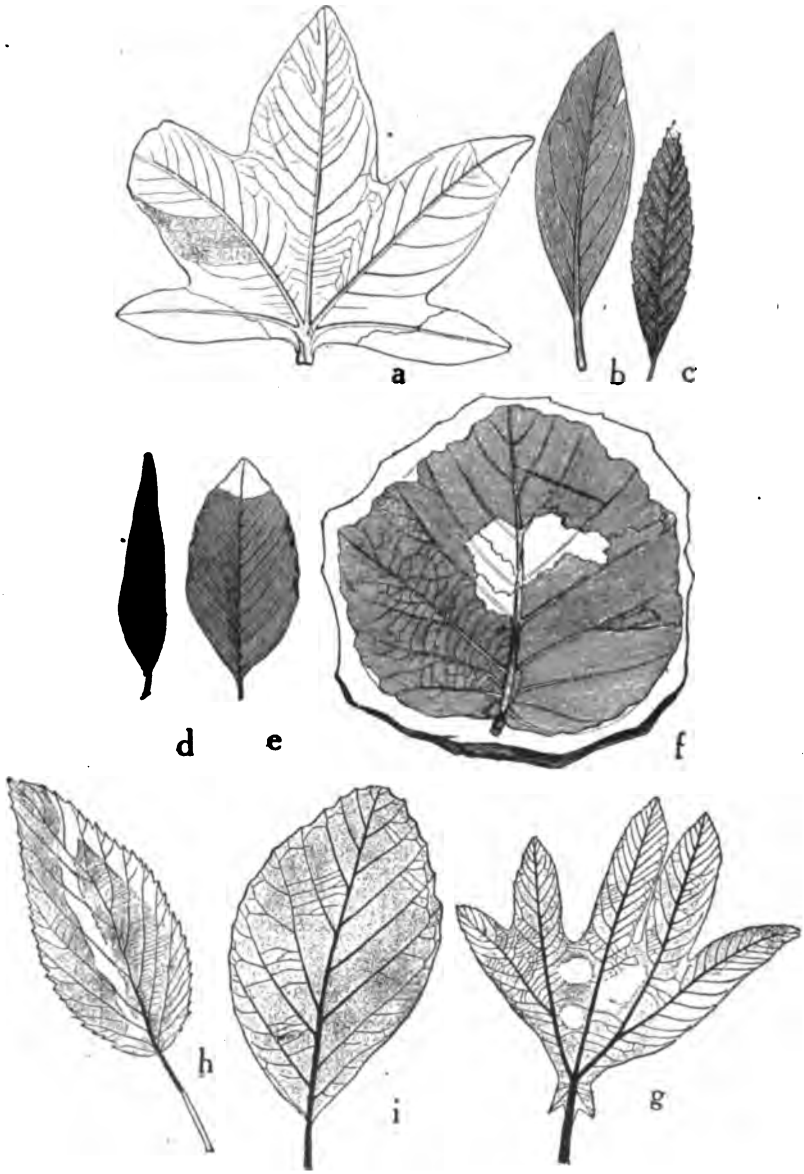


FIG. 1773.—Types of plants of the American Cretaceous.

a–f, Characteristic Middle Cretaceous plants, Dakota group: *a*. Sweet Gum (*Liquidambar integrifolium*); *b*, Laurel tree (*Laurus nebrascensis*); *c*, Oak (*Quercus primordialis*); *d*, Willow (*Salix proteæfolia*); *e*, Beech (*Fagus polyclada*); *f*, (*Protophyllum quadratum*); *g–i*, characteristic Upper Cretaceous plants (Laramie): *g*. Sarsaparilla (*Aralia digitata*); *h*, Arrow-wood (*Viburnum newberrianum*); *i*, Alder (*Alnus grewiopsis*). All reduced. (From Le Conte.)

tinct from that found either in lower or in higher deposits (Fig. 1773 *g–i*). By the close of the Cretaceous, a considerable percentage of the modern angiospermous type of vegetation had become fully established throughout the world, while the ferns, cycads, and conifers had become permanently relegated to subordinate positions. Some of the dicotyledonous angiosperms, such as the magnolias, tulip trees, sassafras, and others, had their maximum development at this time, being much reduced in number and kinds in succeeding periods. The sedges and grasses were, however, still poorly represented in late Cretaceous time, but in the succeeding Tertiary became very important, a fact with which is readily correlated the rapid rise of the grazing mammals.

Invertebrates

There is, on the whole, a very striking change in the invertebrate life of the earth after the close of the Palæozoic. Leaving the **Protozoa** as too little studied, we note that the **sponges** undergo a great development, appearing in vast numbers, especially in the Cretaceous. The Palæozoic types have entirely died out, and many groups which have living representatives, though mostly in deep water, have made their appearance. The *Hexactinellid* and *Lithistid* sponges appear to have been at their acme of development in the Mesozoic, when, judging from the nature of the strata in which they were embedded, they probably lived in shallow water. The calcareous sponges, too, were very abundant, especially in Jurassic and Cretaceous time.

A few of the Palæozoic types of **corals** (*Tetraseptata*) still continued to linger in the Triassic of Europe, but they soon died out completely and in their stead the Hexaseptata arose and became the dominant types. Though simple corals still continued, the compound forms now became far more important. In the Palæozoic the true outer coral-wall, the so-called *epitheca*, was the fundamental structural feature, the septa when developed forming within this wall, as outgrowths therefrom. In the new group of corals, the septa became the dominant structures, the epitheca becoming subordinate, constituting a connecting tissue (*cœnenchyma*) in the compound forms, or disappearing altogether. A new type of wall, the *theca* (originally thought to be the real wall of corals), now arose, formed by cross-plates set between the septa near their outer margin (Fig. 1774).

The **Bryozoa**, too, branched out into new groups, though most of these had Palæozoic representatives. The most pronounced development took place among the cyclostomatous types, which are especially abundant in the older Mesozoic, while at the opening of the Cretaceous the order of the *Cheilostomata* arose which, with the *Cyclostomata*, becomes the leading Mesozoic type of Bryozoa.

A remarkable reduction has taken place among the **brachiopods**, of which nearly all the Palæozoic genera have disappeared. During the Mesozoic, the *rhynchonelloids* and the *terebratuloids* were

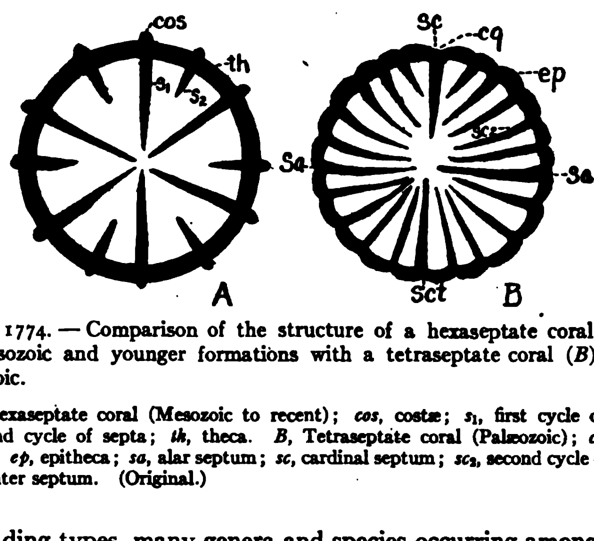


FIG. 1774. — Comparison of the structure of a hexaseptate coral (*A*) of the Mesozoic and younger formations with a tetraseptate coral (*B*) of the Palæozoic.

A, Hexaseptate coral (Mesozoic to recent); *cos*, costæ; s_1, first cycle of septa; s_2, second cycle of septa; *th*, theca. *B*, Tetraseptate coral (Palæozoic); *cg*, costal grooves; *ep*, epitheca; *sa*, alar septum; *sc*, cardinal septum; sc_2, second cycle of septa; *sct*, counter septum. (Original.)

the leading types, many genera and species occurring among these, but few belonging to other groups.

The **pelecypods** also show a striking change. Of the three orders into which this class is divided, only one, the *Prionodesmaceæ*, has an abundant representation in the Palæozoic, and of the 40 families of this order, 14 are practically restricted to it, while 15 families began in the Palæozoic and continued with few exceptions through the Mesozoic and often the Tertiary as well. Eight began in the Mesozoic, only one being restricted to it, while three families are wholly Tertiary and recent. The order *Anomalodesmaceæ* has only one family out of 14, restricted to the Palæozoic. One is restricted to the Mesozoic, five to Tertiary and recent times, and seven originate in the Mesozoic and continue to the present.

Finally, the order *Teleodesmaceæ* has two families, out of 46, restricted to the Palæozoic, while one begins in the Palæozoic and continues to the present. Seven are restricted to the Mesozoic, 12 to the Tertiary and Recent, while the remaining 24 families begin in the Mesozoic and continue to the present. This shows the essentially modern character of this group. The forms restricted to the Mesozoic belong to the family of the *Disceratidæ* (Fig. 1634), *Monopleuridæ* (Fig. 1711), *Caprinidæ* (Fig. 1725), and the rudistid families, *Radiolitidæ* (Fig. 1689) and *Hippuritidæ* (Figs. 1723-1724), together with two families of the *Lucina* series.

The **gastropods** show a similar distribution. The majority of the Palæozoic forms belong to the order *Aspidobranchia*, most of which continue through the Mesozoic and many to the present time. Only two families (*Neritidæ* and *Stomatiidæ*) begin in the Mesozoic and continue to the present. Of the order *Ctenobranchia*, seven of the 42 families have Palæozoic representatives, all of these continuing through the Mesozoic and generally to the present. Two families are restricted to the Mesozoic (*Nerineidæ*, Fig. 1657, and *Columbellaridæ*) and six to post-Mesozoic time. The remaining 27 families begin in the Mesozoic and continue to the present. Of the *Opisthobranchia*, only one family doubtfully begins in the Palæozoic, three are wholly post-Mesozoic, and five begin in the Mesozoic and continue to the present. The *Pulmonata*, or air-breathing gastropods, are mainly Mesozoic and younger, though some Palæozoic types also occur.

Of the **pteropods** the family *Cavolinidæ* (Fig. 891) begins in the Cretaceous and continues to the present. The family *Limacinidæ* is wholly post-Mesozoic, and the *Hyolithidæ* (Fig. 1017) wholly Palæozoic. Of the *Conularida* only the genus *Conularia* (Fig. 1511) has representatives in the older Mesozoic (Triassic and Liassic).

The **cephalopods** are among the most characteristic invertebrates of the Mesozoic, for to it one great division, that of the *Ammonoidea*, is primarily restricted, except for the primitive ancestral (goniatitic) members. Among the *Nautiloidea*, which were so typical of the Palæozoic, there is only one surviving straight or orthoceran form, but a number of open or discoidal nautilicones. With the beginning of the Jurassic, however, only the close-coiled nautiloids survived, the several types being representative of five families, two of which also have Palæozoic members. Only one family, that of the *Nautilinæ*, or the true Nautilus family, survives to the present day, having had its inception in the Jurassic.

In marked contrast with this slight representation of the essentially Palæozoic group of nautiloids is the great diversity of the ammonoids, which, arising in the late Palæozoic, reached their acme in Jurassic time, and completely disappeared at the end of the Cretaceous. The evidence of the derivation of the primitive goniatites from slightly involute Palæozoic (probably early Devonian or late Silurian) nautiloids is clearly shown by the structure of these shells, for the young goniatite has all the characteristics of a *Nautilus* shell, the distinctive goniatite features (lobed suture, ventral position of siphuncle, etc.) not appearing until later in the life of the individual. Types with ceratitic and even with simple ammonitic sutures (see Fig. 1382, p. 467, and Fig. 1451, p. 527) arise in the late Palæozoic, but the ceratitic suture is especially characterisitc of the Triassic types, to which horizon the true *Ceratites* is confined. Forms with more complicated or ammonitic suture also occur in the Trias, but this kind of suture is most characteristically developed in the Jurassic and Cretaceous.

Of the 29 sub-families of ammonoids represented in the Trias, 13 have Palæozoic ancestors, 14 are entirely confined to the Trias, and only two, belonging to the family *Phylloceratidæ*, begin in the Trias and extend into the Jurassic and the Cretaceous. The Jurassic has 22 sub-families, two of which, as just stated, begin in the Trias, 13 are confined to the Jurassic, and eight pass into the Cretaceous. Finally, the Cretaceous has 18 sub-families (or families) seven of which begin in the Jurassic, one in the Triassic, while 10 are confined to it. Thus it is at once apparent that the Triassic ammonoid fauna is still very closely related to that of the late Palæozoic, while a similar close relationship exists between the Jurassic and the Cretaceous. The most pronounced distinction, however, exists between the Triassic and the Jurassic, only one family bridging the gap between them. The Cretaceous, as already outlined in the preceding chapter, is especially characterized by highly ornamented types and by others which, to a greater or less degree, have in the adult lost the power of close-coiling, and some of which (*Baculites*) actually become straight again, except in the extreme young stage. These and the families which show a simplification by retardation of the suture, so that in some cases it remains in the ceratitic stage (*Sphenodiscus*, *Engonoceras*, Fig.

1756 *a–d*), represent declining or degenerating evolutional lines, and this is true also of the forms which developed numerous excrescences on the surface of the shells, the so-called highly ornamented types.

The dibranchiate cephalopods arose in the Triassic from some Palæozoic ancestors (probably *Bactrites*). The oldest forms are the belemnites (Fig. 1673 *a–g*), which became extremely abundant in the Jurassic and Comanchean, but in later Cretaceous time, only two genera (*Belemnitella*, Fig. 1758, and *Actinocamax*, Fig. 1759), survived. Their descendants in the Tertiary are curved forms with a much reduced outer protective "guard," while only one modern form exists (*Spirula*, Figs. 770, 897), which has a loose-coiled shell and no guard. Another order, the *Sepioids*, well represented to-day by squids and cuttlefish (Fig. 894), arose in the Jurassic (or possibly earlier) and rather rapidly reached the specialization possessed by modern types. The earliest octopus type (*Calais*) is found in the Cretaceous of Mt. Lebanon in Syria, but the true *Octopus* and *Argonauta* (Figs. 895, 896) did not appear until the Tertiary.

Trilobites are wholly wanting in the Mesozoic, but other crustacea are frequent, though seldom well preserved. Of the **Branchiopoda** the most characteristic and practically the only representative in the Trias and Wealden is *Estheria* (including *Estheriella*), a fresh-water form. **Ostracoda** (*Cytheridæ*, some of the *Cypridæ*, *Cytherellidæ*, and *Cypridinidæ*), are common in the Jurassic and Cretaceous, and quite distinct from Palæozoic types. Of the **Cirripedia**, the goose-barnacles (*Lepaditæ*, Fig. 929) begin in the Mesozoic and there are several other barnacles in the Cretaceous. The modern acorn barnacle (*Balanus*, Fig. 928) appears first in the Eocene.

Of the higher crustaceans (Malacostraca) the **Isopoda** are well represented in the Mesozoic, having probably Palæozoic ancestors, but true **Amphipoda** are still unknown. The **Decapoda** (lobsters, crayfish, crabs) are, however, well represented and often abundant.

The **Merostomata** are represented in the Mesozoic by the horseshoe-crabs, these being at first fresh-water types, as were their ancestors in the Palæozoic. The modern genus *Limulus* first appears in the Bunter Sandstein of the Vosges Mountains, occurs in the Keuper of Lorraine, and is again well represented in the Upper Jurassic lithographic stone of Bavaria (Fig. 937) and the Jurassic of other parts of Europe. By this time the genus had apparently taken to living in the sea, which is its modern habitat, though even in the Tertiary some species seem still to have inhabited fresh water, as is shown by their occurrence in the brown-coal deposits (Oligocene) of Germany. The **eurypterids** have entirely disappeared, their last representative occurring in the Permian. **Scorpions** and **spiders**, on the other hand, continue through the Mesozoic, as do also the **Myriapoda** and **Insecta**. The ancient families of Palæozoic insects have almost entirely disappeared, and in their stead the modern families have appeared. There are, however, a few families with ancestors in the late Palæozoic, which continue to the present time. The greatest number of the Mesozoic species known has been obtained from the Lias and the Upper Jurassic. Few species are known from the Cretaceous, because of the widespread marine conditions, and still fewer from the Triassic, where aridity seems to have acted as a check.

The stemmed **echinoderms** or *Pelmatozoa* are represented only by the crinoids. Only one stalked family (*Plicatocrinidæ*) has Palæozoic affinities. All of the stalked Mesozoic crinoids belong to the order *Articulata*, and only one of these, the pentacrinoids (Fig. 1676), begins in the Triassic, all the others making their first appearance in the Jurassic. There are, however, three families of floating crinoids, the *Saccocomidæ* of the Jurassic (Fig. 1678) and the *Marsupitidæ* and *Uintacrinidæ* of the Cretaceous (Figs. 1716–1718) which are related to Palæozoic families. Of the other Echinodermata, the *echinoids*, or sea-urchins, are most characteristic, and of these only one order, the *Cidaroidea*, begins in the Palæozoic. Both regular echinoids, with mouth and anus at opposite poles, and irregular ones with the anal opening or both mouth and anus displaced along the median line, are found. Of the 21 existing families 13, or nearly 63 per cent, are represented in the Mesozoic and one only (*Cidaroidea*) in the Palæozoic as well.

Fishes

The Triassic fish fauna still exhibits many resemblances to that of the Permian, the sharks and ganoids being well represented. These include both the heterocercal *Palæoniscidæ* (Fig. 1429) and *Catopteridæ* (Fig. 1570), and the enamel-scaled *Lepidostei* (Fig. 1680). The crossopterygian ganoids, on the other hand, have mostly disappeared except for one family (*Cœlacanthidæ*) which extends to the Chalk and the living forms of Africa. The *Chondrostei*, or cartilaginous ganoids, are also well represented in the Mesozoic (Triassic, Liassic and probably in the Cretaceous). The *Dipnoi*, or true lungfish, were present in the Triassic, while a few *Teleosts* or bony fishes had also appeared. In the Lias, fish remains are abundant, most of them belonging to the scaly ganoids of the order *Lepidostei*, though sharks persist in undiminished numbers. In the Upper Jurassic, where the *Palæoniscids* have been reduced to one genus, the sharks are represented by many genera closely allied to, if not identical with, living forms. *Ganoids* are, however, the most abundant of fishes, these being chiefly the *Cœlacanthids*, the *Lepidostei*, and the *Amiodea*. The *Teleostei* have become more abundant.

FIG. 1775.—*Mastodonsaurus giganteus*. Part of tooth sectioned showing labyrinthodont character. (After Owen.) Lettenkohle (Triassic) Württemberg.

With the beginning of the Cretaceous the ganoids became more and more replaced by teleosts, this replacement being most complete in the Upper Cretaceous (Cretacic) where ganoids were rare and more than three-fourths of the fish fauna consisted of teleosts.

AMPHIBIA

The *Stegocephalia* which were so characteristic of the late Palæozoic, especially the Permian, died out in the Triassic, where they were primarily represented by the labyrinthodonts, so called because of the complicated or labyrinthine tooth structure (Fig. 1775). The only other amphibian from the Mesozoic is an aquatic salamander-like urodele (*Hylæobatrachus*) which has been found in the Wealden of Belgium. True salamanders, together with frogs and toads (*Anura*), do not appear until the Tertiary.

REPTILES

The Mesozoic era was, *par excellence*, the age of reptiles, for at that period of the earth's history these animals reached their maximum development, having since taken a very subordinate place in the life of the earth. In the Mesozoic they dominated not only the land, but the waters and the air as well. Because of their great importance we shall discuss the several orders separately.

Rhynchocephalia. — This order, to which the existing *Sphenodon* or *Hatteria* of New Zealand (Fig. 1776) belongs, is one of the most primitive, and attained its maximum development in the Trias. The oldest members of this order, the *Proterosauria* of the Permian, had much in common with the small stegocephalians from which they were apparently descended. From this primitive type were derived not only the later members of the order, including the grotesque *Pelycosauria* (*Dimetrodon*, *Naosaurus*, Figs. 1561, 1562) of the Permian, but the common ancestor of dinosaurs and birds and the *squamata* (lizards, snakes, etc.) and crocodilians as well. A few of the rhynchocephalians range into the Jurassic and Cretaceous.

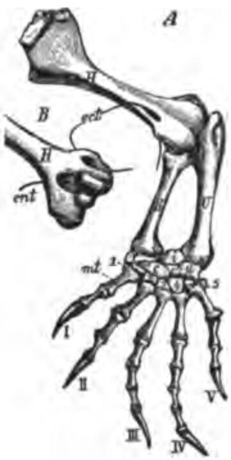


FIG. 1776. — Left fore leg of *Hatteria punctata*, New Zealand: *A*, from above; *B*, from below; *H*, humerus; *ect* and *ent*, foramina epicondiloidea; *R*, radius; *U*, ulna; wrist bones: *c*, c^1, centralia; *i*, intermedium; *r*, radiale; *u*, ulnare; 1–5, carpalia of first to fifth finger; bones of hand: *mt*, metacarpals; I–V, phalanges. (From Steinmann.)

FIG. 1777. — *Platecarpus coryphaeus*, Upper Cretaceous, Kansas; about $\frac{1}{16}$ natural size. Restored after Williston.

Squamata (lizards, snakes, etc.). — Here belong the giant marine lizards, the *Mosasaurs*, which inhabited the Cretaceous seas and which, in their enormously elongated body, suggest the veritable sea serpent (Figs. 1777, 1778). Lizards also appeared first in the Upper Jurassic (Purbeck beds), but these and the Cretaceous remains were of rather doubtful affinities. Remains of snakes are also of doubtful character in the Cretaceous, though they probably size, and fully adapted to a marine habitat. In the plesiosaurs the limbs became modified into paddles and the neck was usually much elongated. These animals were most abundant in Jurassic time, but several types continued into the Upper Cretaceous, where they finally became extinct.

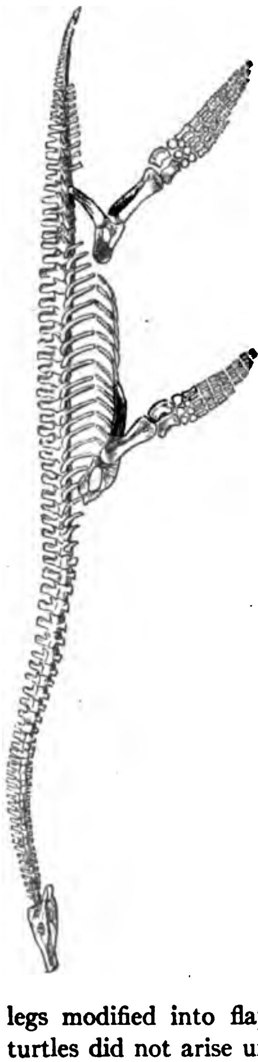


FIG. 1782. — Skeleton of *Plesiosaurus dolichodeirus* much reduced. (Jurassic.) Europe.

Theromorpha. — This order includes a series of mammal-like land forms, most of which go back to the Permian but also range into the Triassic, and which may include the stem forms, from which other types of reptiles have been derived. There are three groups: the *Cotylosauria* with solid skulls, the *Pelycosauria*, or fin-backed lizards, and the *Theriodontia* (Fig. 1564 *a–c*), the last including members with many primitive mammalian characters, which suggest that this group gave rise to the earliest or egg-laying mammals.

Chelonia (turtles, etc.). — Turtles appeared suddenly in the Upper Trias and were fairly well represented in the Jurassic and Cretaceous, continuing through the Tertiary to the present time. The oldest known forms have almost all their characteristic features, so that there must have been a long, still unrecorded earlier history. At present there is no indication of the manner in which, and the type from which, they were derived. In the Jurassic the turtles had a world-wide distribution (Fig. 1684), and in the Cretaceous marine turtles with the legs modified into flappers made their appearance. True land turtles did not arise until the Tertiary.

Crocodilia. — The crocodiles possess the highest internal organization known among reptiles. The earliest (Triassic) forms, the *Parasuchia* (Fig. 1783), are with difficulty distinguished from rhynchocephalians, from which they probably arose. Another Triassic suborder is that of the *Pseudosuchia*, which were especially abundant in western Europe. On a slab of sandstone from the Upper Trias, now in the Stuttgart Museum, twenty-four individuals of *Aëtosaurus* are preserved in complete though slightly

FIG. 1783. — Skull of *Belodon kapffi*, an ancestral crocodilian of the Upper Triassic (Keuper). Stuttgart, $\times \frac{1}{12}$.

A, orbit; *L*, antorbital foramen; *N*, external narial opening; *S*, lateral temporal fossa. (After Steinmann.)

crushed condition, the largest having a length of 86 cm. True crocodiles occurred in Jurassic and Comanchean time (*Teleosaurus*, Fig. 1784) and in Cretaceous and Tertiary times (*Eusuchia*). To this last suborder also belong the modern forms. In both suborders long and broad-snouted forms occur, but the short and broad-snouted types did not appear until the Upper Jurassic, all the older forms being longirostrate or long-snouted.

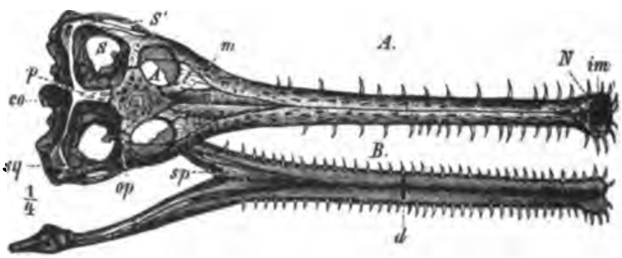


FIG. 1784. — *Teleosaurus cadomensis*. A crocodile from the Jurassic (upper Dogger or Bathonian). Caen, Calvados, France.

A, skull from above; *B*, lower jaw from above. *A*, orbit; *S*, supra-temporal fossa; *S*[1], lateral temporal fossa; *N*, anterior nares; *l*, lachrymal; *p*, parietal; *f*, frontal; *n*, nasal; *op*, post-orbital; *sq*, squamosal; *co*, basi-occipital; *sp*, splenial; *d*, dentary; *im*, premaxillæ. (After Steinmann.)

Dinosauria. — The dinosaurs, or terrible lizards, were without doubt the most remarkable and important reptiles of the Mesozoic, to which age they are wholly confined, so that it is equally correct to speak of the Mesozoic as the age of dinosaurs. Their ancestry is probably to be sought in the Permian *Proterosauria*, which in turn appear to have arisen from still earlier cotylosaurians. Two great divisions (often called orders) of dinosaurs are recognized,

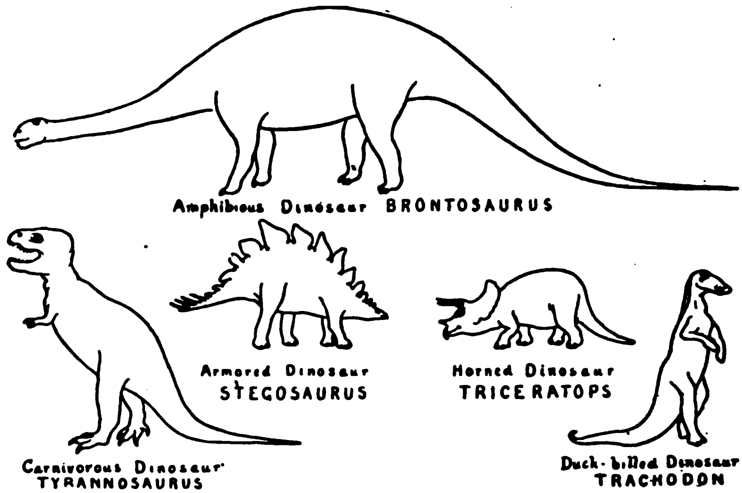


FIG. 1785 *a.* — Outline restorations of dinosaurs to show their relative sizes. Scale about nineteen feet to the inch. (After Matthew, *Dinosaurs.*)

the *Saurischia*, in which the structure of the pelvis or hip was crocodile-like, and the *Ornithischia*, which had a pelvis similar to that of birds. These are regarded as having arisen separately

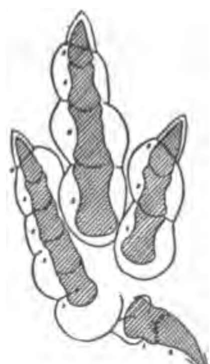


FIG. 1785 *b.* — Dinosaur foot-print (*Anchisauripus exsertus*), ½ natural size. Upper Triassic of the Connecticut Valley. The bones are indicated in the shaded portions. (After Lull.)

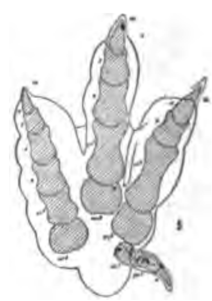


FIG. 1785 *c.* — Dinosaur foot-print (*Gigandipus caudatus*), $\frac{1}{12}$ natural size. Upper Triassic sandstones of the Connecticut Valley. The bones of the foot are given in shaded portion. (After Lull.)

from a common ancestor. In size these animals ranged from that of a chicken to monsters 80 feet or more in length, and their life was spent either upon the land or partly submerged in shallow water. Some dinosaurs were herbivorous, others carnivorous. (Fig. 1785 *a*.)

The *Saurischia* include the oldest known dinosaurs, and this group underwent fewer changes than the other one, throughout the Mesozoic, the chief modification being a progressive increase in size of the body, and proportionate decrease in the length of the fore-limbs. The mode of progression was therefore bipedal (except in the Sauropoda), and their foot-prints are those of the

FIG. 1786. — Restoration of *Podokesaurus holyokensis*, about $\frac{1}{18}$ natural size. (After Lull.)

hind legs. Here belong many of the foot-prints found in the Connecticut Valley sandstones and in those of New Jersey, which, on account of their three-toed character (the fourth one seldom made an impression), were originally regarded as bird tracks (Fig. 1785 *b, c*). Some of these animals were small, one (*Podokesaurus*, Fig. 1786), the skeleton of which has been found in the Triassic sandstones of Massachusetts, being about four feet long with the tail occupying more than half its length, while the animal's hind legs were long and the fore legs were very short. A still smaller form was *Compsognathus*, about 2½ feet long, found in the Jurassic beds of the Solnhofen district (Eichstätt, Bavaria). Other forms, known by skeletons from the Triassic of the Connecticut Valley, were larger (5 to 8 feet) with clawed hands, like *Anchisaurus* (Fig. 1787) of the suborder *Pachypodosauria;* other members of this group occur in Europe. Both these groups were carnivorous. A third carnivorous division of the *Saurischia* is that of the *Theropoda* or beast-footed dinosaurs. They were active runners upon their hind limbs, and had a powerful and heavy tail, which acted as a counterpoise. One of the largest of these (*Allosaurus*, Figs. 1788–1790), the skeleton of which was found in the Comanchean beds of Como Bluff near Medicine Bow, Wyoming, and is now mounted in the

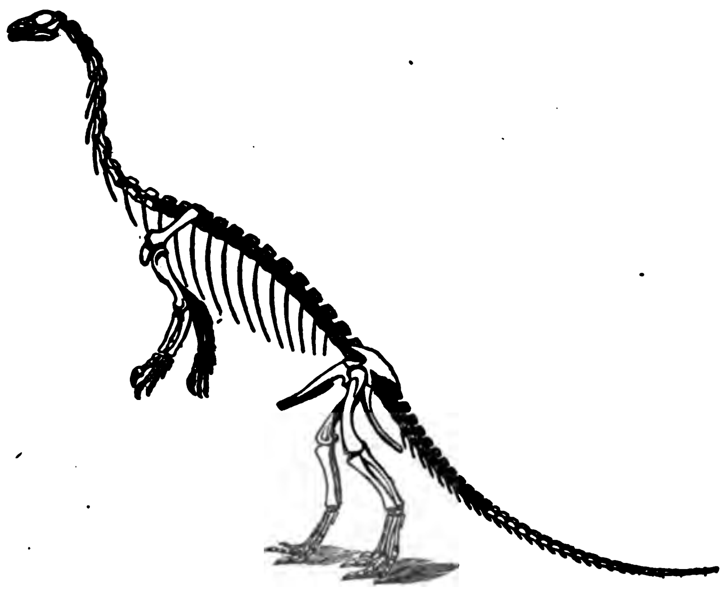


FIG. 1787. — The skeleton of *Anchisaurus colurus*, restored, $\frac{1}{18}$ natural size. Triassic Connecticut Valley. (After Marsh from Lull.)

American Museum, New York City, has a length of 34 feet, 2 inches, and a height, when resting on all four feet, of 8 feet, 3 inches. The jaws of this creature were loosely hung, enabling it to open them widely, and either to swallow its prey entire, or to tear it into huge chunks. For this purpose the teeth were powerful and recurved, and both hands and feet were furnished with strong curved claws (Fig. 1790). This group also included a form which developed a compressed horn-like process upon the nose (*Ceratosaurus*).

But by far the most terrible of the theropodous dinosaurs was the great Tyrant King of the saurians, the *Tyrannosaurus rex* (Figs. 1791–1792), which has been referred to as representing "the climax of evolution of the giant flesh-eating dinosaurs" (Matthew), and the largest flesh-eating land animal that has

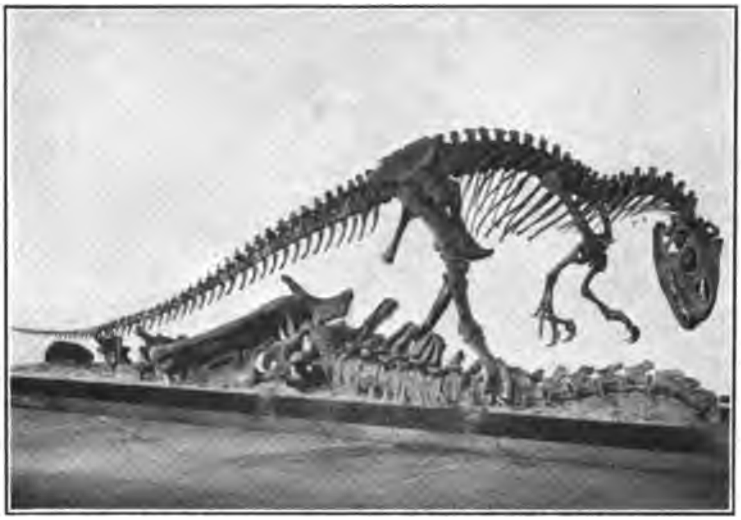


FIG. 1788. — A Comanchean carnivorous dinosaur, *Allosaurus*, mounted in the attitude of feeding upon the carcass of a *Brontosaurus*. The fossil bones of the latter were found to be scored and scratched as though by some sharp-toothed enemy, and near the skeleton were found the broken-off teeth of an *Allosaurus*, which were of the size and shape to make such marks on the bones of its prey. (Courtesy of the American Museum of Natural History.)

FIG. 1789. — Restoration of the dinosaurs shown in Fig. 1788; *Allosaurus* was of gigantic proportions, being 34 feet, 2 inches in length, and 8 feet, 3 inches high. This dinosaur was bipedal, the fore feet having been used only for fighting or tearing the flesh from the bones of its prey, but not for walking or support. (Courtesy of the American Museum of Natural History.)

FIG. 1790. — *Allosaurus fragilis*, Comanchean (Atlantosaurus beds of the Morrison) Rocky Mts. *A*, hind limb; *B*, fore limb, $\frac{1}{18}$ natural size; *co*, coracoid; *il*, ileum; *is*, ischium; *m*, metatarsus; *p*, pubis; *pp*, postpubis; *sc*, scapula. (From Steinmann.)

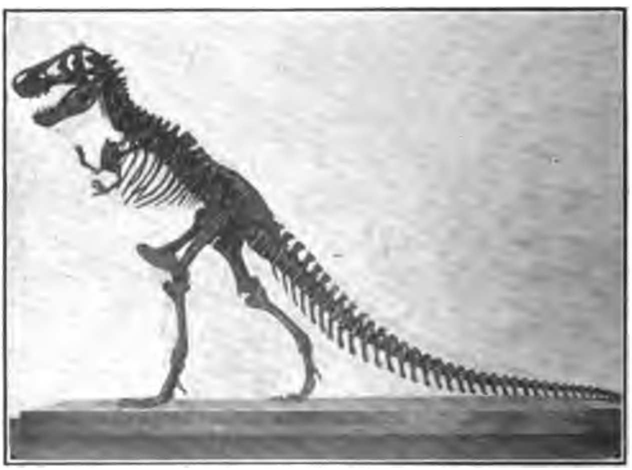


FIG. 1791. — Skeleton of *Tyrannosaurus rex*, the tyrant king of the saurians, measuring 47 feet in length and 18½ feet in height. The specimen was found in a sandstone in the Cretaceous "Bad Lands" of Montana, and incompleté skeletons have been found in beds of the same age along the Red Deer River in Alberta, Canada. (Courtesy of the American Museum of Natural History.)

FIG. 1792. — *Tyrannosaurus*, the largest known terrestrial carnivorous dinosaur, approaching a group of three-horned herbivorous dinosaurs (*Triceratops*). The latter was one of the horned Ceratopsia which developed a stout armor of heavy plates, a neck-frill, and horns which served both for offense and defense. At the same time the "tyrant" saurians evolved a different type of offensive mechanism in their great bulk, their powerful jaws, and their stout claws. (Courtesy of the American Museum of Natural History.)

FIG. 1793. — A small, agile, carnivorous dinosaur (*Ornitholestes* = bird robber) holding in his claws a primitive toothed bird. From the Comanchean (Como Bluff beds) Wyoming. (Courtesy of the American Museum of Natural History.)

ever existed. Its length was 47 feet and its bulk equal to that of a mammoth or a mastodon. It had massive hind limbs which supported the entire weight of the body and, when standing, its

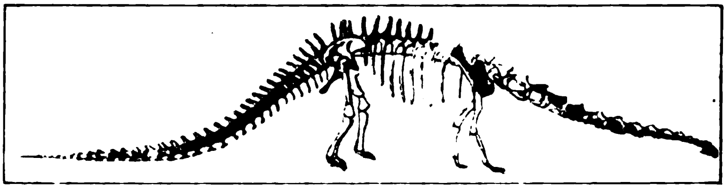


FIG. 1794. — The skeleton of *Diplodocus* in the American Museum of Natural History. The actual skeleton parts preserved are shaded, the other parts are restored. Scale 1 inch = 16 feet.

height was 18 to 20 feet. Its large head, over four feet in length, its huge teeth, 3 to 6 inches long and an inch wide, and its sharp claws, made it a most formidable and terrible opponent. This creature, of which a nearly complete skeleton from the Cretaceous of western North America is preserved in the American Museum of Natural History, was probably of slow-moving habit, preying upon the huge and ponderous herbivorous dinosaurs of the period. One of the smallest of flesh-eating dinosaurs was the agile *Ornitholestes* (Fig. 1793), the remains of which were found in the Comanchean beds of Como Bluff, Wyoming.

FIG. 1795. — *Diplodocus longus*, Comanchean (Morrison), Rocky Mountain region.

A, skull from the side; *B*, from above; *A*, orbit; *L*, posterior, *L'*, anterior antorbital foramina; *N*, nasal opening; *S*, supra-temporal fossa; *S*, lateral temporal fossa; one-tenth natural size. (After Steinmann.)

In the Comanchean deposits of the western United States have been found the remains of the herbivorous members of the *Saurischia*, the sub-order of the *Sauropoda* or reptile-footed dinosaurs. These were all quadrupeds, the four stout legs supporting the huge body, from which projected at one end the long and often heavy neck, with its absurdly diminutive head, and on the other the equally long, bulky tail, which in *Diplodocus*

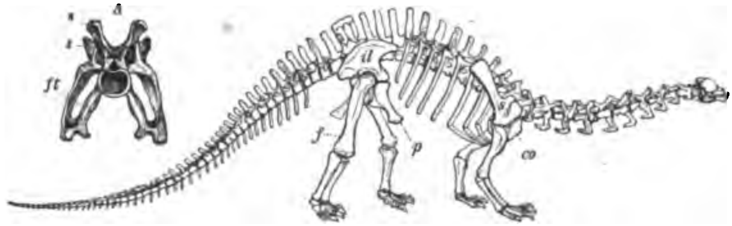


FIG. 1796. — *Brontosaurus excelsus*, Comanchean, Rocky Mountain region, about $\frac{1}{130}$ natural size. *A*, single cervical vertebra (posterior view) $\frac{1}{45}$ natural size.

co, coracoid; *f*, femur; *il*, ileum; *p*, pubis; *s*, scapula; *ft*, foramen transversarium; *s*, anterior and *s'*, posterior articulating process. (From Steinmann.)

(Figs. 1794–1795) appears to have ended in a whiplash ten feet in length. The length of a specimen of this genus reached 87

FIG. 1797. — A sauropod (amphibious) dinosaur of Morrison age, *Brontosaurus* (*Apatosaurus*). A heavy-limbed, quadrupedal, herbivorous form believed to have lived on the flood-plains and in the lagoons of Comanchean time, in the region now elevated into the Rocky Mountain chain of Wyoming and Colorado. (Courtesy of the American Museum of Natural History.)

feet, and its appearance must have been like that of a huge snake, the middle part of whose body was swollen to elephantine proportions and supported on four short pillar-like legs. *Brontosau-*

rus (Fig. 1796), the "thunder lizard," another huge sauropod from these deposits, was far more bulky, with thicker neck and tail, and therefore much heavier, one with a length of 66 feet, 8 inches, having had an estimated weight of 38 tons (Fig. 1797). This creature probably consumed in the neighborhood of 700 pounds of plant food per day, if the food was in the same proportion to its bulk and weight, as in the case of modern herbivores. As these animals had teeth only in the forward margins of their jaws (Fig. 1795), the food was apparently not masticated, but bolted

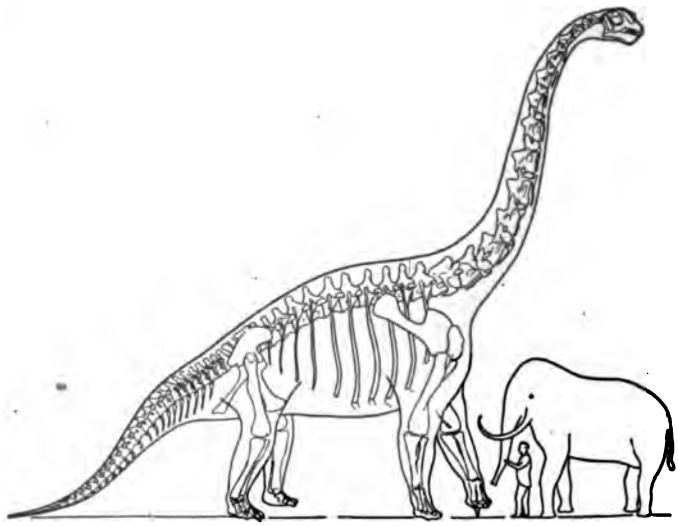


FIG. 1798. — *Brachiosaurus*, the largest known dinosaur. Sketch reconstruction from specimens in the Field Museum in Chicago, and the Natural History Museum in Berlin. The other figures are given for comparison of sizes. ($\times \frac{1}{180}$.) (After W. D. Matthew.)

intact as torn from the vegetation of the period. To assist the reduction of this food, they apparently swallowed large stones, for such stones, highly polished, and foreign to the country rock, have occasionally been found within the ribs of these animals. The largest of these herbivorous creatures has been obtained from East Africa (*Gigantosaurus* or *Brachiosaurus*, Fig. 1798), the length of this animal having been estimated at 120 feet, though some authorities have much reduced this. This animal was especially characterized by long and huge fore-limbs, which raised the front part of the body in a giraffe-like manner. As all these huge Sauropoda probably lived partly submerged in the land waters of the period, this creature was able to wade out to a considerable depth, and still keep its head above the water. This

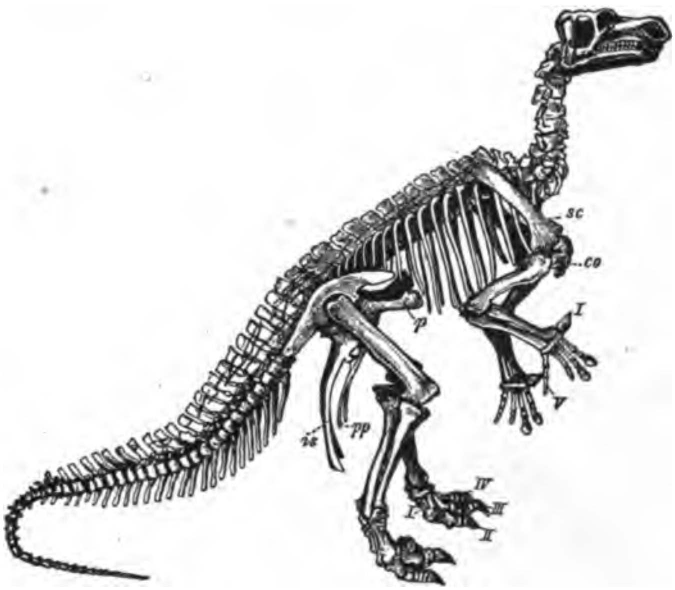


FIG. 1799. — *Iguanodon bernissartensis*, Comanchean (Wealden), Belgium. Skeleton about $\frac{1}{70}$ natural size. *co*, Coracoid; *is*, ischium; *p*, pubis; *pp*, postpubis; *sc*, scapula; I–V, digits. (From Steinmann.)

aquatic habitat was probably resorted to in order to escape from the numerous carnivorous dinosaurs which occupied the land.

A remarkable fact is the early extinction of these huge beasts, for they appear to have been confined to the Comanchean. Their destruction may have been due to the submergence of the lands by the encroaching sea, thus reducing the food supply, or it may have been a case of the natural dying out of a race which had developed to extremes of bulk and specialization, — which, in other words, had reached racial old age.

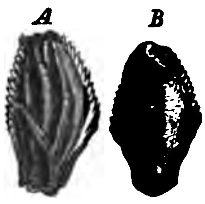


FIG. 1800. — Tooth of *Iguanodon bernissartensis*. *A*, outer, *B*, inner side. One-half natural size. (From Steinmann.)

The dinosaurs of the order *Ornithischia*, also called *Predentata* (on account of the toothless predentary bone which united the two halves of the lower jaw in front), were exclusively feeders upon plants, and they had teeth in the rear of their jaws only (Fig. 1805).

have been found in western America, and these have shown that the skin was without defensive armor, being thin and covered with

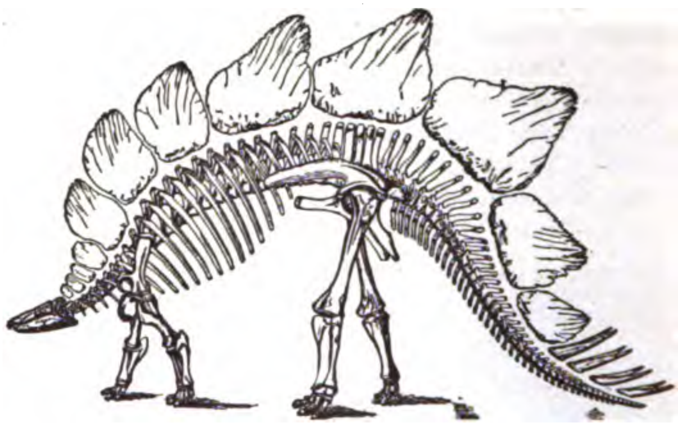


FIG. 1803.—*Stegosaurus ungulatus* (after Marsh). (×1/80.) Comanchean, Wyoming.

small tubercle-like scales (Fig. 1802). The four-fingered hands were webbed, and possibly the feet also. The oldest Ornithopoda are

FIG. 1804.—*Stegosaurus*, the huge armored, plant-eating dinosaur as it appeared in its native haunts in Comanchean time. (Courtesy American Museum of Natural History.)

known only from their foot impressions in the Triassic rocks of the Connecticut Valley, where the small five-fingered fore-feet occur among the larger three-toed impressions of the hind-foot.

or bird-footed group, comprising bipedal unarmored forms, which used their shorter limbs to rest upon, and also for grasping and pulling down the branches on which they fed. Characteristic members of this group were *Camptosaurus* from the Comanchean of western United States and the Jurassic and Comanchean of Europe, which ranged in length from 7 to 17 feet; *Iguanodon* (Figs. 1799–1800) from Europe, one of the first dinosaurs known to science, a form about 34 feet long with strong three-toed running legs, and powerful arms with four fingers and a spike-like thumb on each; and finally the duck-billed dinosaur, *Trachodon* (Fig.

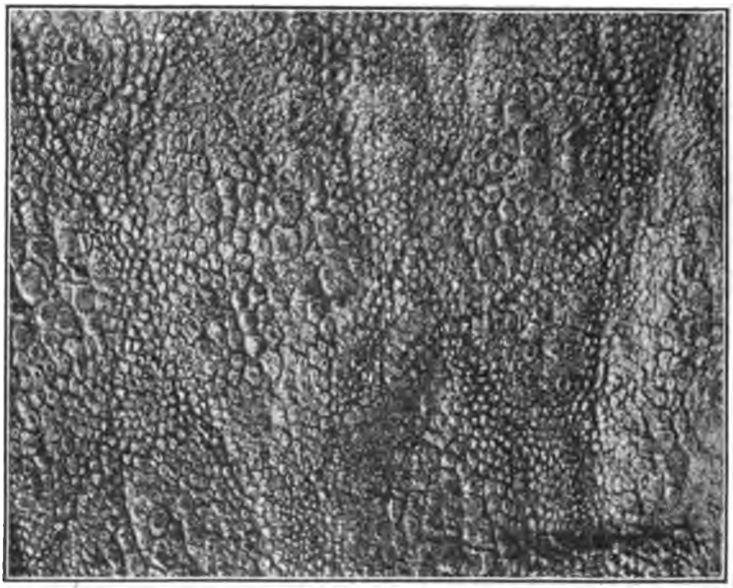


FIG. 1802. — Detail of the skin of the dinosaur "mummy" (*Trachodon annectens*). The animal appears to have died a natural death, its carcass being exposed for a long time to the sun, which parched and dried it until the tough skin was drawn in close around the skeleton. Later the remains were buried in a bed of river sand and clay, which preserved the Cretaceous "mummy" intact. See Fig. 1801 and Frontispiece. (Courtesy of American Museum of Natural History.)

1801 and Frontispiece), which lived towards the close of the Cretaceous, the contemporary of the *Tyrannosaurus*, from which it was able to escape only by its fleetness of foot, and the fact that its tail was a powerful swimming organ, and probably enabled the animal to escape in open water. Mummified specimens of this animal capacity of *Stegosaurus* must have been of a very low order, for the seat of its intelligence was no greater in volume than that of a three-weeks-old kitten (Williston). Other members of this division, however, exhibited less extremes of development and their armor was more like that of modern crocodiles.

FIG. 1807. — *Triceratops*, the last of the dinosaurs, in its native haunts on the Upper Cretaceous plains of western North America. Its huge horns and great bony frill over the neck adapted it for both offensive and defensive operations. (From the painting by Charles R. Knight made under the direction of J. B. Hatcher.)

The last, and in many respects most extreme of the Ornithischia, was the group of horned four-footed dinosaurs or *Ceratopsia*. These had much the appearance of mammals, of rhinoceros-like aspect, with a length of 20 to 25 feet in *Triceratops* (Figs. 1806–1807), the

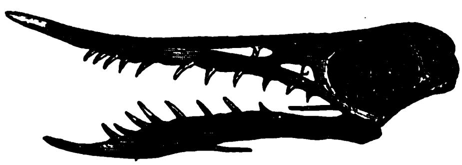


FIG. 1808. — *Rhamphorhynchus gemmingi*, Upper Jurassic, Lithographic beds of Solnhofen. Side view of skull.

A, orbit with sclerotic ring; *L*, antorbital foramen; *N*, external nasal opening; one-half natural size. (After Steinmann.)

late Cretaceous representative of the group. This had three horns upon the large head, one of these on the nose and one above each eye, while the rear of the skull was developed into a huge bony frill or crest, which served as a protection for the neck when the animals were fighting among themselves, and for the attachment of powerful muscles. In the earlier forms the frontal horns were less developed or were rudimentary, but the nasal one was always strong. In the later forms the nasal horn became reduced and entirely obsolete in one form (*Diceratops*). The Ceratopsia, so far as known, were entirely confined to the Cretaceous rocks of western America, and they, in company with all the other surviving dinosaurs, suffered an apparent sudden and complete extinction at the end of that period, so that not one of them remained to witness the rise of mammalian life in the Tertiary eras.

Pterosauria. — The winged saurians, the dragons of the air, were likewise confined to the Mesozoic. Their means of flight was bat-like rather than bird-like, but unlike the bat, where the wing membrane is stretched between the fingers (except the first) and thence to the legs, the flying membrane of the pterosaurs was supported only by the enormously enlarged last finger of the hand, from which it extended to the legs and tail (Fig. 1683, p. 681). The jaws of these animals were, in many species, furnished with powerful conical teeth (Fig. 1808) and the fingers and toes generally ended in claws. The oldest known family (*Rhamphorhynchidæ*) of this group is long-tailed and belonged to the Jurassic. It is represented by *Rhamphorhynchus* (Figs. 1638, 1808) from the lithographic rocks of Bavaria, while

FIG. 1809. — *Dimorphodon macronyx*. A bat-like lizard. Lower Lias, Lyme Regis, England.

A, orbit; *L*, antorbital foramen; *N*, nasal opening; *S*, lateral temporal fossa; I–V, toes; *F*, wing supporting fingers; *h*, humerus; *s*, scapula; *u*, ulna; one-eighth natural size. (From Steinmann.)

other related genera have been found in the Jurassic of England, one of them (*Dimorphodon*, Fig. 1809) appearing in the lower Lias. None

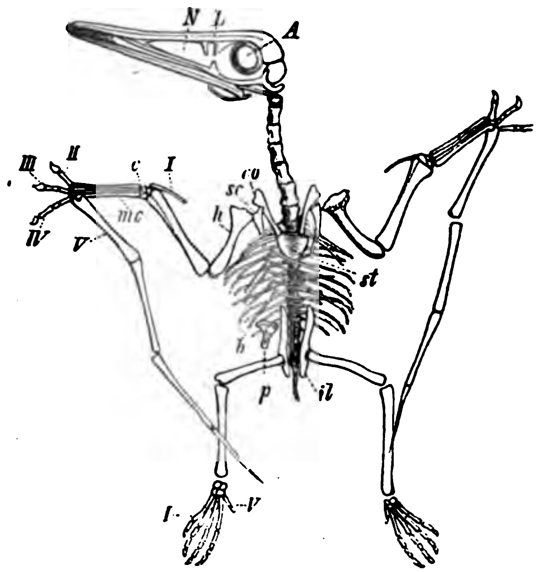


FIG. 1810. — *Pterodactylus spectabilis*, the smaller flying lizard. Upper Jurassic, Lithographic beds, Solnhofen. Skeleton from ventral side. $(\times \frac{2}{3}.)$

A, orbit; *L*, antorbital foramen; *N*, nasal openings; *b*, ribs; *c*, carpus; *co*, coracoid; *h*, humerus; *il*, ilium; *mc*, metacarpus; *p*, pubis; *sc*, scapula; *st*, sternum; I–V, digits, modified in the hand for wing supports. (From Steinmann.)

of these have been found in America. They were all rather small. A second family, the *Pterodactylidæ*, comprised short-tailed animals, some of them no longer than a sparrow. This family includes the

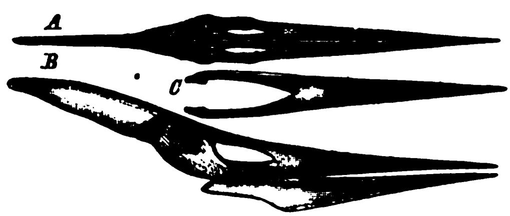


FIG. 1811. — *Pteranodon longiceps*, Upper Cretaceous, Kansas. *A*, skull from above; *B*, from side; *C*, lower jaw; *a*, eye socket. $\frac{1}{10}$ natural size. (From Steinmann.)

European *Pterodactylus* (Figs. 1683, 1810) of the Upper Jurassic and the American *Nyctodactylus* from the Cretaceous (Niobrara of

Kansas) which was toothless and had a wing expanse of about two meters, and another less well known form from the American Comanchean (Como beds of Wyoming). The third family, the last

FIG. 1812. — Skeleton of the Giant Flying Reptile, the *Pteranodon*, as mounted in the American Museum of Natural History. This specimen was found in the Cretaceous chalk of western Kansas. It is 16 feet from tip to tip of the wing. The bones are very thin and fragile, and it is thought that the animal did not weigh more than 25 pounds. The missing parts are painted in the background, and the supposed outlines of the wings restored in a lighter tint. (After W. D. Matthew.)

of the order, includes the huge *Pteranodon* (Figs. 1811–1813) with a spread of wings of six meters and a long, sharp toothless beak. The remains of this animal have been found in the Niobrara (Creta-

FIG. 1813. — The Giant Flying Reptile, *Pteranodon*. Restoration drawn under the supervision of the late Dr. S. P. Langley, of the Smithsonian Institution. The little white gull-like birds are *Ichthyornis* — one of the toothed birds of the Cretaceous. (See Fig. 1817.)

ceous) beds of Kansas. In England a similar form has been found in the Cretaceous strata together with the genus *Ornithocheirus*, which differs only in the presence of well-developed teeth in both jaws. Fragments of skeletons of several other forms have been found in the Wealden, and in the Upper Jurassic (Purbeck) beds of England.

As the Pterosauria appeared suddenly and fully developed in the Jurassic, their ancestry must go back to the Triassic, though at present no remains of these animals are known from rocks of that age.

Birds

The Mesozoic era witnessed the rise of birds from a primitive reptilian ancestor, from which probably the dinosaurs also arose.

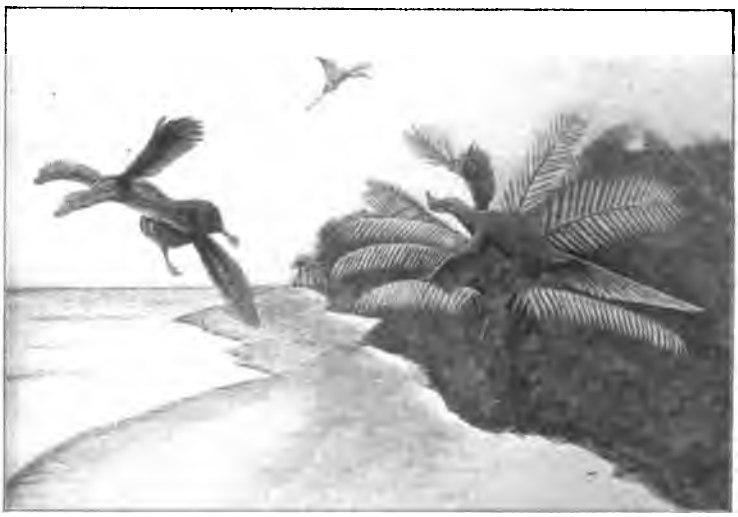


Fig. 1814. — Restoration of the earliest known bird, *Archæopteryx*. The landscape depicted is such as might have been seen along the shores of one of the Jurassic lagoons in the Solnhofen region, Bavaria. Along the beach is shown a low jungle consisting mainly of cycads with a few tall ferns and conifers. In the distance, high up in the sky, is seen a small, winged lizard or pterodactyl (*Rhamphorhynchus*). In the foregound to the right, an *Archæopteryx* is depicted perched upon the crown of a cycadophyte tree (*Zamites*). It holds a small fish in its toothed jaws, and grasps the tree-top with its finger-like claws. To the left may be seen an *Archæopteryx* flying, its slender, reptile-like body being balanced by the long, broad tail. (After Berry.)

The oldest known remains of birds are those of the famous *Archæopteryx* (Fig. 1639, p. 664), represented by two individuals from the lithographic stone of Bavaria (Upper Jurassic). This bird was about the size of a crow, was well feathered, and probably a fair flyer (Fig. 1814). Though undoubtedly a bird, it had still many reptilian characters, among which were the presence of teeth in both jaws, the free, clawed fingers of the hand, the fully developed

FIG. 1815. — *Hesperornis regalis*, restored ($\times \frac{1}{10}$). Cretaceous. (After Marsh.)

breastbone, and especially the long, vertebrated, reptilian tail, which was, however, furnished on both sides with a row of feathers. In all later birds the tail is short, and the feathers are disposed fan-wise.

In the Lower Cretaceous (Niobrara) of Kansas, several other birds have been found, all of which still retained their teeth. The largest of these, *Hesperornis* (Figs. 1815–1816), 4½ feet in length, had lost the power of flight and had developed powerful hind limbs, well adapted for wading and swimming. Its wings and shoulder-girdle were reduced, the forearm and hand being entirely lacking, and the breastbone was without a keel. The other well-known form, *Ichthyornis* (Fig. 1817), was a small, tern-like or gull-like bird, a good flyer, and of modern aspect, except that, like *Hesperornis*, its jaws still bore teeth. In both, however, the forward part of the upper jaw was toothless. The appearance of these birds is suggested in Fig. 1813.

FIG. 1816. — Tooth of *Hesperornis regalis*, with the young tooth which grows upward to replace the old tooth when it is worn down. (×5.) (After Marsh.)

FIG. 1817. — A Cretaceous bird, *Ichthyornis victor*, restored. About one-fourth natural size. (After Marsh.)

MAMMALS

Mammals became differentiated from reptiles by the development of characters which insured increased activity, as a result of which a warm-blooded condition arose. The cause for this has been found in the increase of aridity towards the close of Palæozoic time, which rendered speed necessary to traverse the arid wastes, and further, the coming on of the glacial epoch at that time created conditions under which only those that could best retain their bodily heat were able to survive. Hence a covering of hair, the distinctive external feature of the mammal, arose. The essential mammalian characters had probably been developed from the reptilian ancestors by the end of Permian or in early Triassic time, and it is probable that Africa was the original home of these animals.

In late Triassic time both Germany and the eastern United States had been invaded by the primitive mammals, and they apparently reached western America in Comanchean time, and

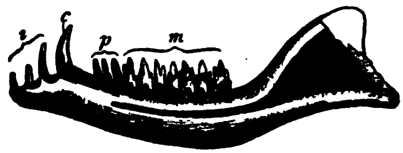


Fig. 1818.—*Dromatherium silvestre*, a primitive mammal of the Upper Triassic of North Carolina; right lower jaw. *i*, incisors; *c*, canine; *p*, premolars; *m*, molars. Twice enlarged. (From Steinmann.)

continued into the Cretaceous. In general these mammals were small, the largest hardly exceeding a rat in size. Some had sharp-pointed teeth and probably lived on animal food. Others had teeth fitted for an herbivorous diet, with sharp cutting-teeth (*incisors*) in front, and broad-crowned grinding teeth (*molars*) behind. Some may have lived on dinosaur eggs and so contributed to the extermination of their huge contemporaries. In

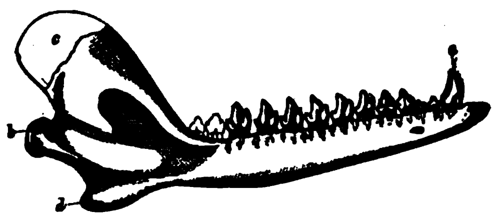


Fig. 1819. — Right lower jaw of *Diplocynodon victor* (after Marsh), outside view (×¾). *a*, canine; *b*, condyle; *c*, coronoid process; *d*, angle. Comanchean, Como Bluff, Wyoming.

habit they were probably largely arboreal, living mainly in the forest-clad swamps and river deltas (Matthew).

The primitive mammals are classed as follows: *Protodonta*, with dentition more of a reptilian type (*Microconodon* and *Dromatherium*, Fig. 1818) of the Upper Triassic coal horizon of North Carolina); *Triconodonta*, with the molars bearing a large median and two smaller cusps, one in front, the other behind (linear series), these forms being found in the Jurassic of England and the Comanchean of Wyoming; *Multituberculata* (Allotheria), with a single pair of rodent-like cutting or incisor teeth above and below and with molars bearing two or three longitudinal rows of tubercles. They occur in the Lower Triassic of Europe, the Lower Jurassic (Karoo) of Africa, and the Comanchean of Europe and North America, as well as the Cretaceous and Eocene of this country. The fourth group, the *Trituberculata* (Pantotheria), with molars having three cusps arranged in a triangle (Fig. 1819), were probably insect eaters, and their remains are known from the Jurassic of England and the Comanchean and Cretaceous of North America.

CHAPTER XLV

THE TERTIARY SYSTEMS

In the days of Werner, the rocks and loose sands which covered the Chalk, the highest of the Secondary or Flötz formations, were designated *Angeschwemmt-gebirge*, a term roughly translatable by *Alluvium*. In Italy and elsewhere these formations were generally classed as Tertiary, while the Nummulitic limestones of the Pyrenees and Alps, now recognized as a part of the Lower Tertiary, were classed as a part of the Chalk.

In 1810, MM. Cuvier (portrait, Fig. 6, p. 24, Pt. I) and Brongniart described the geological formations which underlie Paris, and which consist of a succession of horizontally lying sands, clays, limestones, marls, gypsum, etc., some of them with the remains of marine animals, others with the remains of fresh-water or terrestrial forms. They are well exposed in many ravines and other natural sections in the country around Paris, and because of their finely preserved fossils, they had attracted the attention of naturalists generally. The formations were traced from outcrop to outcrop, and were found to have the same succession, and were further recognized in the different sections by their fossils. When the shells from these deposits were studied by Lamarck (portrait, Fig. 7, p. 25, Pt. I), it was found that they were almost all of species unknown in the modern seas, while their nearest affinities were with those of the warmer waters. The bones and skeletons of land-animals, some of them of large size, which were found in these deposits, especially the gypsum, were studied by Cuvier, and declared by him to be distinct, not only specifically, but for the most part generically as well, from any hitherto observed in the living creation.

Shortly after this, the clays and sands which lie in the triangular depression in which London is situated (London Basin) and similar sands and clays of Hampshire and the Isle of Wight, on the south coast of England (Hampshire Basin), were examined, and their fossils compared with those of the Paris Basin. It was found that the greater number of species in the two regions were specifically identical, and essential contemporaneity of the formations of these regions was thus recognized.

The publication of these studies, and the descriptions and illustrations of these fossil shells and bones in a great series of monographs and in the *Dictionnaire des Sciences Naturelles* and Lamarck's *Histoire Naturelle des Animaux sans Vertèbres*, turned the attention of naturalists in other countries to the little-altered fossils in their superficial formations. These formations were at first assumed to correspond essentially to those of the Paris Basin, because like them, they generally rested directly upon the Chalk. When, however, the shells in these deposits were studied in detail, it was found that this correspondence was by no means a marked one in all cases. A pronounced difference in specific characters was especially noted by the Italian geologist Brocchi, in the shells so abundantly preserved in the low hills of sandy strata which flank the Apennines on both sides, from the plains of the Po to Calabria, hills to which he gave the name of Sub-Apennines. Subsequently, in 1825, the French geologist de Basterot examined the shell-bearing strata exposed in the neighborhood of Bordeaux and Dax, in the south of France, and found the shells to differ specifically from those of the Paris Basin and those of the Sub-Apennine hills as well. It appeared that these south of France shells were of an intermediate character, between the Parisian and the Italian species, and it was not long before the actual superposition of the strata in which they occur, upon the extension of the Parisian strata, was found, especially in the Valley of the Loire, while in Piedmont, beds with the fossils of the Bordeaux region were found to underlie others with the fossils of the Sub-Apennine formations. It thus became evident that a threefold division of the Tertiary strata was possible, and to these three divisions Sir Charles Lyell (portrait, Fig. 12, p. 27, Pt. I) in 1833 gave distinctive names. He called the oldest, those of Paris and London, *Eocene*, signifying dawn of the recent, because they contained only a small proportion of living species of Mollusca (about 3½ per cent). The next division, comprising the formations of Bordeaux, the Gironde, and the Loire, he called the *Miocene*, signifying less recent, because they contain a minor proportion of recent species of Mollusca (about 17 per cent), while those of the

Sub-Apennines, which contain a much larger number of recent species of Mollusca (35 to 50 per cent) he called *Pliocene*, signifying more recent. Lyell had found in Sicily thick formations in which the number of species of Mollusca identical with modern forms constituted from 90 to 95 per cent of the whole, and these he called *Newer Pliocene*, referring the Sub-Apennine formations to the *Older Pliocene*. These Sicilian or Newer Pliocene beds are now classed by some as oldest Quaternary, though others still retain them as Upper Pliocene.

The percentage of recent species of Mollusca found in the several divisions made by Lyell no longer holds true, but the fact remains that these divisions are faunally as well as stratigraphically distinct and, in the opinion of some, are entitled to the rank of systems. Between the original Eocene and Miocene divisions, and partly composed of the beds formerly referred to the top of one and the bottom of the other, lies another division of equal rank, to which in 1834 the German geologist von Beyrich (portrait, Fig. 1820) gave the name *Oligocene* (signifying few recent species). Finally, in 1874, the naturalist Schimper recognized the importance of distinguishing the oldest Tertiary rocks as a separate division preceding the Eocene, and he proposed the name *Palæocene* for it.

Fig. 1820. — E. Beyrich

Subdivisions

The Tertiary or Cenozoic as now recognized is divided into five systems, which naturally fall into two major divisions, the Older Tertiary or *Eogene*, and the younger Tertiary or *Neogene*.

Table of Tertiary Subdivisions

Neogene or Younger Tertiary	Pliocene or Pliocenic
	Miocene or Miocenic
Eogene or Older Tertiary	Oligocene or Oligocenic
	Eocene or Eocenic
	Palæocene or Palæocenic

We shall discuss these under their two main subdivisions, the Eogene and the Neogene. The principal formations of the American Tertiary with their European equivalents are given in the table facing this page.

The Tertiary of North America

The Palæocene Disturbances

The Palæocene is not always recognized by American geologists,[1] who class it as Lower or Basal Eocene. The known deposits of

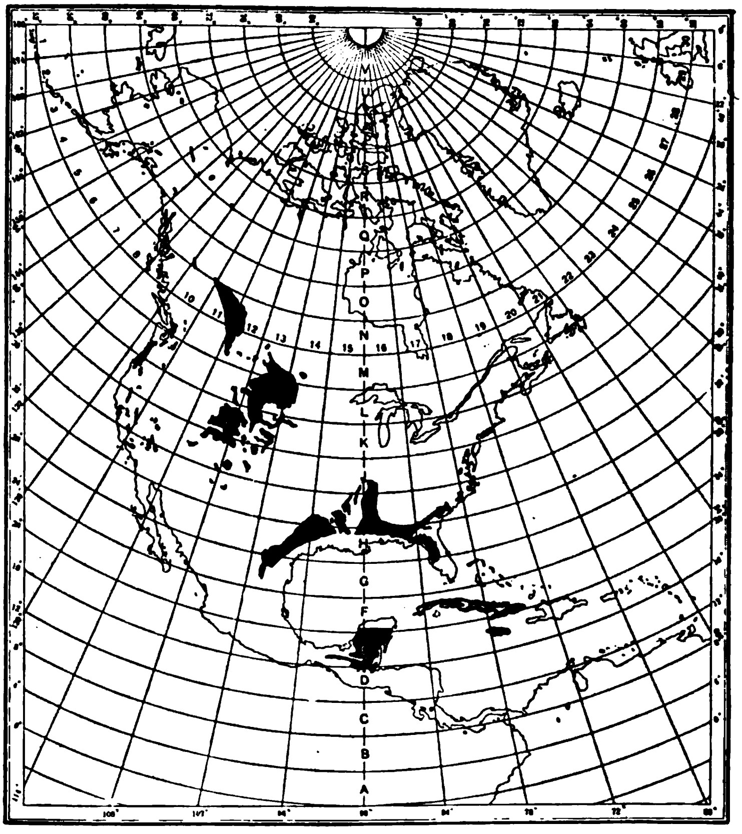


Fig. 1821. — Map showing the outcrops of the earlier Tertiary rocks (Eocene and Oligocene) in North America. (After Bailey Willis.)

[1] The desirability of recognizing it has recently been strongly urged by Dr. W. D. Matthew.

TH THEIR EUROPEAN EQUIVALENTS

Coast	Interior North America (Continental)	European Equivalents
ɔrmation formation	*c.* Loup River (Neb.) *b.* Blanco (Tex.) *a.* Thousand Creek (Nev.); Rattlesnake (Ore.); Republican River	*c.* Sicilian *b.* Astian *a.* Plaisancian
Etchegoin, ılitos forma- at base)	Loup Fork (Mont.); Madison Valley (Mont.); Clarendon (Tex.)	Pontian
rmation Washington t)	Deep River (Mont.); Pawnee Butte (Col.); Mascall (Col., Ore.)	Vindebonian
mation	Upper Arikaree (S. Dak., Neb.); Upper Harrison (Neb.); Upper Rosebud	Burdigalian
p formation	Lower Harrison (Neb.); John Day (Ore.); Upper White River (Great Plains)	Aquitanian (Chattian)

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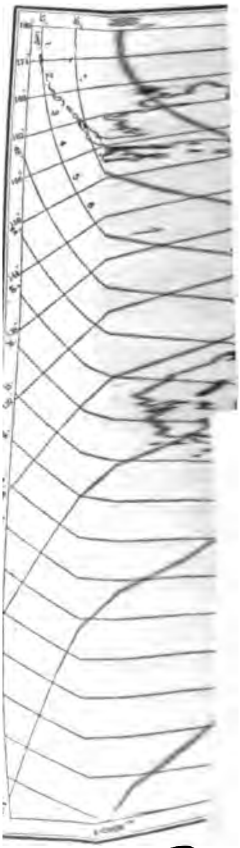

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[1] The desirability of recognizing it has recently been strongly urged by Dr. W. D. Matthew.

this period are few and not extensive, for in the regions now accessible, the time was mainly occupied by withdrawal of the sea, by folding or elevation of the older strata, and by erosion. Elsewhere in the sea, of course, deposits of this period were accumulating.

The Gulf Region. — The Palæocene marks the culminating point of the retreatal movement of the sea inaugurated in late Cretaceous time. This movement was coincident with a period of folding of the strata within the old Cretaceous geosyncline of the Gulf region, as is shown by the fact that the Cretaceous beds of the Greater Antilles are strongly folded, while the Tertiary beds are deposited upon the eroded surfaces of these folds. There is some indication on the Island of Jamaica that folding may have occurred at intervals during the whole of Palæocene time or even later, for strata of that age appear to be involved in some of the folds.

The old Palæocene mountain chain which resulted from the folding of these strata began in the east as a single range, as shown in eastern Porto Rico, but divided toward the western end of that island into a northern and a southern chain. The southern one can be traced through the elongated Haitian peninsula of Jaemel to Jamaica. It appears again in Honduras on the Central American coast, where the strike of the folded strata points to Jamaica. It is true that a great water body separates the Honduran end of this old chain from the west Jamaican end, but this depression, as well as that between the Antilles, is of comparatively recent origin, and there seems to be no reason for doubting that in Palæocene, and probably also Eocene time, this southern range extended continuously from Porto Rico or farther east to Honduras, and thence with a westward trend across Guatemala, Chiapas, and Tehuantepec, where it joined other Mexican ranges. The second or northern range can be traced through northern Haiti, and remnants of it appear in the Sierra Maestra of southern Cuba. This line of strike can be followed through the Cayman group of islands, the bank of Misteriosa, and probably through Swan Island to the center of the Gulf of Honduras (Bay of Amatique), where the Honduran mountain chain of similarly folded rocks rises abruptly and continues westward through Guatemala. This line of folding may not have come into existence until Eocene time, or it may have become accentuated toward the close of the Eocene.[1] Possibly another, though less pronounced range, extended through Cuba, curving southward at its western end and continuing east of Yucatan to British Honduras.

The development of this series of folds from the strata in the old Cretaceous geosyncline of the Gulf region appears to have been accompanied by the depression of the old Cretaceous land on the north, resulting in a more or less continuous water body between this new-formed mountainous land and the landward end of the present Atlantic coastal plain of the southern United States. In this channel the known older Tertiary strata of the region were deposited. Another water body, the Caribbean, lay to the south and in part submerged the north coast of South America as in Cretaceous time.

The Andean Chain. — During the Palæocene, the strata of the Andean geosyncline of western South America likewise underwent a folding, this being the first appearance of the Andes Mountains, and during much of the remainder of the Tertiary, these mountains underwent erosion, ending with the formation of a peneplane, which in late Tertiary time was bodily elevated, warped, and cut by erosion into the present ridges and peaks of the Andes.

A new geosyncline appeared to the west of these newly formed Andes, and in this the marine Tertiary strata (chiefly later Tertiary) of western South America were deposited.

The West Coast Ranges. — Folding also affected the Cretaceous and older strata of the western or Cordilleran geosyncline, for we find that in Washington, Oregon, and parts of California an unconformity separates the Eocene and Cretaceous systems. Elsewhere in California, however, the two horizons are separated only by a disconformity, and in some sections, Palæocene strata apparently follow conformably upon uppermost Cretaceous beds (Danian).

The Interior and Rocky Mountain Region. — A disturbance (Laramide Revolution of Schuchert) with extensive folding also affected the interior regions of western North America at this time, producing the main mountain ranges and intermontane valleys of this area, though a more recent disturbance has also occurred. The Palæocene folding produced the Rocky Mountain chains, and a parallel series, extending more or less continuously from western Wyoming to Mexico, where it joined the extensions of

[1] Vaughan holds that the main disturbances in the Antilles took place at the end of Eocene time.

the Antillean ranges already referred to. The old land area between the Coloradoan and the western geosyncline was apparently arched into a broad anticline and broken into a series of north-south blocks which, by tilting, became the block-mountains of the Great Basin region (p. 749, Pt. I). The western border of this faulted region was marked by the eastward-facing fault scarp of the Sierra Nevadas, and the eastern by the westward-facing scarp of the Wasatch Mountains. Movements continued in this region more or less throughout Tertiary time and in some parts appear to be still in progress. Within this great interior region, as well as in the intermontane valleys and in the remnant of the Coloradoan geosyncline east of the Rockies, only continental strata were deposited during Tertiary time.

It is thus seen that the Palæocene was primarily a period of crustal movements and deformation, resulting in the development of great mountain chains, chief of which were the Mexico-Alaskan, the Andean, and the Antillean, though these latter may be in part of late Eocene or early Oligocene age. The Appalachian Mountain region was lifted bodily without deformation, and the great erosion cycle began, which carved the present mountains and valleys, including those of the Great Lakes, the Hudson, the Susquehanna, and the other transverse and longitudinal valleys of the Appalachians.

The disturbances in some sections may have begun in late Cretaceous time, when, as shown in the Coloradoan geosyncline, the deposition of the *Laramie* beds marks the beginning of the elevation of the land and the retreat of the sea. In some sections it appears to have begun only some time after the opening of Palæocene time, as in New Jersey, where strata regarded as early Palæocene (*Shark River*) rest with apparent conformity upon late Cretaceous beds. In still other regions, as in the Gulf coastal plain, the movement may have ceased in early Palæocene time, for strata classified as of this age rest disconformably upon Cretaceous beds. But on the whole, the disturbances in America, as in Europe, apparently took place mainly in Palæocene time, but with later repetitions. Volcanism accompanied or followed these disturbances in the western United States, where outpourings of lava characterized this period, a line of volcanoes extending from Mexico to Canada, while others broke forth in the Andean region of South America.

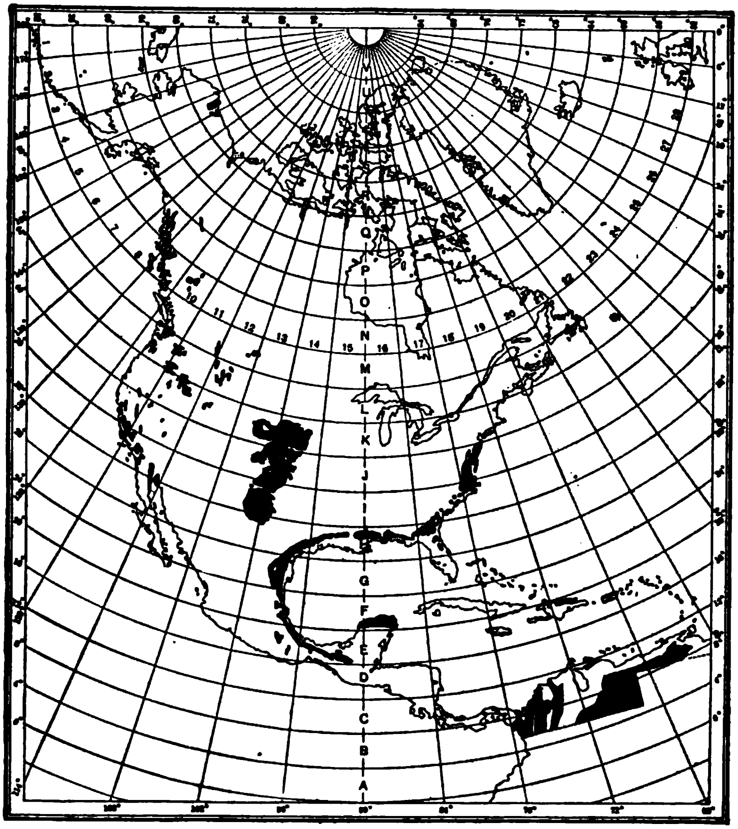

FIG. 1822. — Map showing the outcrops of the later Tertiary rocks (Miocene and Pliocene) in North America. (After Bailey Willis.)

Tertiary Deposits of the Gulf and Atlantic Coast

In the table facing page 782 the principal Tertiary deposits of North America and their European equivalents are listed. Of these, only the Gulf and Atlantic coast deposits on the east, and the Pacific coast deposits on the west, are marine, those of the interior being wholly of continental character. The beds of the Gulf coast appear to be only the overlapping edges of those which were deposited in the geosyncline to the north of the Antillean chain, while those of the Atlantic coast were probably formed on the open sea coast, similar to the modern deposits of this region, with which they have much in common.

Palæocene. — The oldest Palæocene formation appears to be the *Shark River* group of glauconite sands and marls found in New Jersey, where it rests with apparent conformity upon the Upper (marine) Cretaceous, and still retains some of the late Cretaceous organisms. On the Gulf coast, the *Midway* and *Wilcox* groups have been referred to this horizon. The Midway consists of 300 to 450 feet of glauconite sands, clays, and limestone, the latter disappearing inland by replacement with marine, and in some sections fresh-water, clays and sands. The Wilcox is often a cross-bedded sand. It contains much lignite (hence the name *Lignitic group*, formerly applied to it). Beds of clay also occur, and there are not infrequently fossiliferous layers. The maximum thickness of these beds is in the neighborhood of 900 feet.

Eocene. — This begins in the Gulf region with the *Claiborne* group of sands and calcareous clays, etc., often rich in organic remains, especially mollusks. There is sometimes an erosion interval between it and the Wilcox (Georgia) and elsewhere, the older rocks are overlapped, and the Claiborne rests upon the Cretaceous. Westward and northward the series merges into lignite sands. It is succeeded by the *Jackson* calcareous marls and limestones up to 600 feet thick. These, too, are replaced westward by sands of non-marine origin (*Catahoula sandstone* of Texas).

On the Atlantic coast of Virginia and Maryland the Eocene is represented by the *Pamunkey* formation of sands, marls, and clays (225 feet thick) which rests disconformably upon the Cretaceous and is disconformably succeeded by Miocene deposits. Here the sea encroached only in Eocene time and then retreated again, while in the Gulf region deposition was more nearly continuous, but also in shallow water. These deposits extended into northern Mexico. Upper Eocene beds (*St. Bartholomew* formation) are known only from Cuba, where they apparently represent the transgression of the sea over the Antillean land.

Oligocene. — This is wanting on the Atlantic coast north of South Carolina, but is well represented in the Gulf coast, where it includes the *Vicksburg* limestone-series (Lower Oligocene) and the *Chattahoochee* formation (Middle and Upper Oligocene) of clays, marls, and limestones, the latter often highly phosphatic.

Middle and Upper Oligocene beds are also found in Cuba, in Santo Domingo, and in Porto Rico, and it is probable that in

Oligocene time a considerable part of the old Antillean land was submerged.

Miocene. — Marine Miocene beds (*Chesapeake* formation) mainly sands and clays, with an abundance of fossils, chiefly mollusks, were deposited upon the Eocene of the Atlantic coast, but they represent only the Upper Miocene. There is thus a great hiatus between the Eocene and the Miocene, for the upper beds of the Eocene of this region (*Pamunkey* formation) are not younger than Claiborne. The later Miocene beds also locally overlap the older members of the Upper Miocene of this region, showing progressive advance of the sea. In South Carolina the Miocene beds are often highly phosphatized, forming an important source of phosphate rock.

In the Gulf coast states, on the other hand, Lower Miocene beds (*Alum Bluff* beds) rest conformably upon the Oligocene beds, but are followed disconformably by Upper Miocene, the Middle Miocene and generally the early Upper Miocene being absent. This indicates that the sea did not withdraw from this region until toward the end of Lower Miocene time and then returned in the late Upper Miocene, when it also advanced on the Atlantic coast.

Lower and Middle Miocene beds are also well developed in the Antilles, where they follow apparently conformably upon the later Oligocene. Upper Miocene deposits appear, however, to be absent here. Thus the retreat and readvance was not uniform, but the basins were apparently subjected to tilting or warping.

Pliocene. — Marine Pliocene beds are found only from North Carolina southward and westward to Florida, beyond which the known Pliocene beds are non-marine, though marine beds may occur under cover of the younger deposits. They are found, however, in Mexico, especially in Tabasco, Chiapas, and Yucatan. In the Carolinas they are represented by thin fossiliferous marls (*Waccamaw* beds), and in Florida by similar marls of no great thickness (*Nashua* and *Caloosahatchee* beds). Above them lie non-marine later Pliocene beds. Marine conditions thus continued for a time in the Pliocene, after which the final retreat of the sea from the present land-surfaces took place.

Tertiary Deposits of the Caribbean Region

In early Tertiary time the Caribbean Basin was apparently quite distinct from the Gulf-of-Mexico Basin on the north, and it may have been separated from the Atlantic as well by a land ridge along the line now occupied by the Lesser Antilles (Caribbean Arc). This basin was bounded on the north by the Antillean land-mass, and on the south by the oldland of northern South America. It was repeatedly connected with the Pacific across Central America, and in later Tertiary time became confluent with the Gulf Basin on the north. Its depth was probably slight in Tertiary time, the present great depths of this region being of recent origin.

The first connection with the Pacific occurred, according to Vaughan, in mid-Eocene time, and continued through the late Eocene. A similar connection existed in mid- and late Oligocene time, becoming more limited in the early Miocene, and disappearing by the rise of the Central American lands in mid- and later Miocene time. Probably a narrow interoceanic connection existed in Pliocene time, which admitted an Atlantic fauna into the present site of the Gulf of California.

These connections are shown not only by the fact that similar organisms occur in the deposits on both sides of the Central American barrier, but also by the presence of limestones and other deposits of these periods on Panama.

The Tertiary deposits of Jamaica, of southern Santo Domingo, and of southern Porto Rico, are probably to be regarded as the marginal deposits along the northern boundary of this Caribbean Tertiary sea. The first extensive deposit which rests upon the folded and eroded older series is of Vicksburg or early Oligocene age, though there may also be some late Eocene. The Oligocene age of the lower beds is indicated by the presence in them of the large foraminifer, *Orbitoides* (*Lepidocyclina*) *mantelli* (Fig. 1823 *b*), on the south side of Porto Rico and on Jamaica. This occurrence suggests a partial connection with the Gulf Basin on the north, where this species was a characteristic rock-builder. Subsequently the connection was apparently interrupted, for the beds with *Orbitoides* are followed in southern Porto Rico by Lower Miocene (*Chipola*) beds, the Middle and Upper Oligocene being absent. On Jamaica the beds with *O. mantelli* are followed by the great white *Montpelier* limestone, about 1000 feet thick, and remarkable in that it is composed chiefly of foraminiferal shells, with sponge spicules and fine calcareous particles, representing essentially a chalk. No terrigenous material and no mollusk or other large shells occur. Such a rock indicates peculiar conditions of deposition. It can scarcely be of deep-water origin, but may represent the deposits of a stagnant sea into which only pelagic organisms were carried. This would imply that at that time the Caribbean Basin was largely isolated. Panama then was formed of a ridge of igneous rock on which rested sands and muds with marine

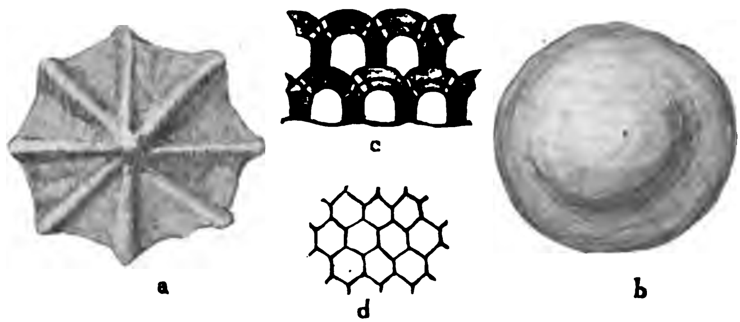

FIG. 1823. — Characteristic types of orbitoid Foraminifera from the Gulf coast and Antillean region of North America. *a*, *Orbitoides* (*Orthophragmina*), a stellately-marked form, with elongate rectangular lateral chambers. Oligocene. *b–d*. *Orbitoides* (*Lepidocyclina*) *mantelli*, outline and a few of the small cells or "lateral chambers" seen in a horizontal section or worn specimen; enlarged to show their hexagonal form. Lower Oligocene. (After Cushman.)

fossils. Limestones with large Foraminifera (*Orthophragmina*, Fig. 1823 *a*) on both sides of the Isthmus represent a late Eocene or early Oligocene submergence.

In apparent accordance with the hypothesis that the Caribbean was a stagnant, enclosed body of water into which pelagic organisms were carried (somewhat like the Black Sea, but not so deep), is the fact that the oldest Tertiary deposit of northern South America (the southern margin of the old Caribbean) consists of continental clays and sands with plant remains and of higher sands with Foraminifera. Some of these beds contain petroleum, which would be the natural product of decay of organic matter in a stagnant sea. It is not impossible that the asphaltum of Trinidad dates in part, at least, from this period.

The later Oligocene beds of this basin are normally marine, as is shown by the richly fossiliferous limestones which overlie the Montpelier chalk of Jamaica. At that time the connection with the Pacific was established and fossiliferous deposits (*Culebra* formation) were forming on Panama. This condition continued into the Miocene (*Gatun* formation of Panama), when richly fossiliferous deposits were formed on most of the islands of the Antilles, and when probably the continuity of the Antillean land-mass had been broken, so that both the northern and southern water bodies were in intercommunication. At that time, too, the neo-Andean geosyncline, formed to the west of the young Andes Mountains, was flooded, for there Miocene strata with the Caribbean fauna, but also with Pacific and North American elements, rest directly upon metamorphic older rocks (Chile, Peru, etc.).

The oscillations of the sea in this region are shown by the fact that the early Miocene (*Bowden* marls of Jamaica, and equivalent (Chipolan) beds of southern Porto Rico) rests disconformably upon the Oligocene and is in turn disconformably succeeded by beds of Pliocene age. The Upper Miocene, represented upon the Atlantic coast by the *Chesapeake* formation, is everywhere wanting in the Antillean region and in Central America, as well as to a large extent in the Gulf coast region. This marks a great withdrawal of the waters due to elevation of the region. North and South America were joined by Central America, and the Greater Antilles were joined to one another and possibly to Central America, by the reappearance of the old land bridges from Jamaica to Honduras and from western Cuba to Yucatan, while a connection with South America along the Caribbean Arc also occurred. While this disturbance was pronounced and deformed the strata, it was not nearly so marked as the older one at the opening of Tertiary time. Matthew, however, does not think that the mammals of the Antilles bear out these connections, and it is quite possible that the land bridges were incomplete, the continued migration from South America being prohibited by open channels.

This period, too, was probably one of stagnant waters in the Caribbean, so that organic matter no doubt accumulated in the more central portions and subsequently produced the petroleum and other hydrocarbons which found their way into the adjoining porous strata. It is conditions of this kind which were probably responsible for the formation of the extensive Trinidad asphalt deposits which impregnate the Miocene rocks.

Tertiary Deposits of the West Coast Geosyncline

In Washington, Oregon, and parts of California the Eocene and Cretaceous strata are separated by an unconformity, and Palæocene beds are mostly absent, but elsewhere in California these seem to be included in the oldest sediments (*Martinez*) which rest with apparent conformity on late Cretaceous strata. The *Martinez* and *Tejon* are mostly sandstones and clays, the former between 1000 and 2000 feet in thickness, the latter ranging from 1400 to 2300 feet. The upper beds of the Tejon often abound in

FIG. 1824. — Quarry in the diatom deposits of the Miocene (Monterey) at Lompoc, California. The diatoms occur in enormous numbers, and their organic matter is believed to be the source of the California petroleum. (After Jordan.)

diatoms and Foraminifera, but shells of *Pecten* and other Mollusca also occur. In some localities carbonaceous shales with a brackish water fauna are included in the Tejon. All these facts point to shallow water and occasional lagoonal conditions with stagnant water in which the Foraminifera and diatoms were deposited, much as they are in the Black Sea to-day, though the depth was probably not so great as in that water body. That the water was stagnant or else highly saline, and therefore without those animals which live upon the dead organic matter of the diatoms and Foraminifera, is shown by the fact that the organic matter is preserved in the form of petroleum, which now saturates the immediately overlying

FIG. 1825. — A bluff of uniform thin-bedded Miocene shale (Monterey) on the coast of California, at Lighthouse Point Conception. (U. S. G. S.)

sands of the *Vaqueros* formation (Miocene), these forming the chief sand of the Coalinga oil district.

In some sections the Tejon overlaps the Martinez and rests upon the older rocks, even upon granites and gneisses. In still other

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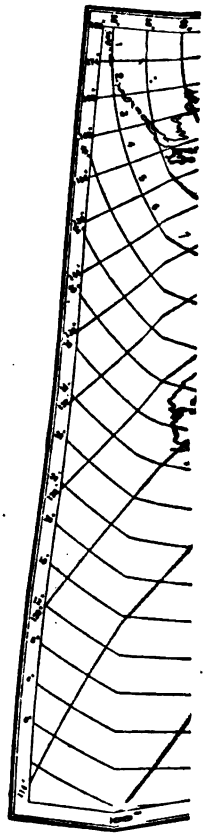

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areas and is in places 5400 feet thick. This is a hard, flinty shale in the lower, and a more chalky rock in the upper, part, in which almost the only fossils are diatoms and Foraminifera, shells of Mollusca and other animals being almost entirely absent, though these abound in the rocks below and above. Moreover, the organic matter of these diatoms and Foraminifera was not destroyed, as it would have been if there had been bottom animals to act as scavengers, or a free circulation of the water to produce oxidation, and it thus appears that during the deposition of this formation the physical conditions there differed considerably from those which preceded or followed (Figs. 1824–1826).

It has been suggested that these accumulations of pelagic organisms occurred in deep oceanic waters (half a mile or more), which at this period existed in California, similar to the oceanic depths of from 2700 to 6000 meters in which such organisms accumulate to-day. It is extremely doubtful, however, if these deposits accumulated in such oceanic depths, though fairly deep but enclosed bodies of water may have existed. The absence of these deposits in some sections, and the fact that elsewhere gypsiferous beds are found in them, while the whole series is more or less impregnated with salt, suggest stagnant and probably highly saline lagoonal waters, into which these pelagic organisms were carried, as such organisms are carried into similar water bodies to-day, and this is further indicated by the preservation of the organic matter as petroleum. Remains of fish and other pelagic vertebrates are also found, and occasionally remains of sharks and claws of crabs occur, all these animals apparently perishing in the unfavorable environment of these water bodies. Such enclosed basins would readily be produced by a slight warping of the previously normal sea-bottom. That such changes were in progress in the coastal geosyncline is shown by the fact that in the state of Washington the 4000 feet of Lower Miocene shallow-water marine beds are folded and faulted and followed unconformably by 2000 feet of Upper Miocene shallow-water marine strata, the mid-Miocene, that is, the period during which the Monterey beds were deposited in the south, being here characterized by emergence. A subsidence after the formation of these peculiar deposits would submerge the barriers and restore the normal marine conditions. Such a restoration is shown in the fossiliferous Upper Miocene deposits (*San Pablo* formation) and the sands with oysters, pectens, barnacles, and other shallow-water forms of the *Santa Margarita* formation (possibly late Middle Miocene) of other sections.

The Pliocene in the more southerly region consists of a thousand feet or more of conglomerates, sandstones, and clay slates, with shallow-water marine fossils, and further north (Coalinga district) of several thousand feet of marine, fresh-water, and subaërial deposits (*Tulare* formation). Much volcanic material occurs in the Pliocene of the coast ranges.

the close of the Eocene.[1] Possibly another, though less pronounced range, extended through Cuba, curving southward at its western end and continuing east of Yucatan to British Honduras.

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FIG. 1828. — Pulpit rock. An erosion monument in continental Eocene strata, Echo Cañon, Utah. (U. S. G. S., courtesy of *Popular Science Monthly*.)

FIG. 1829. — General view of Big Bad Lands, South Dakota. Eroded continental Tertiary strata. (U. S. G. S., courtesy *Popular Science Monthly*.)

FIG. 1830. — Bluff of "Protoceras sandstones" in the Bad Land region of South Dakota. Continental Upper Oligocene. (U. S. G. S., courtesy *Popular Science Monthly*.)

FIG. 1831. — Erosion remnants ("Teapot and cup") of finely laminated Green River shales capped by hard brown sandstone. Upper Palæocene. Wyoming. (U. S. G. S.).

intermontane basins were subject to arid conditions, with the result that certain of the beds then deposited are now red, while in other sections extensive beds of rock-salt were formed (Fig. 1827). In these deposits were buried the remains of the mammals and other animals of that period, but marine Tertiary formations are

Fig. 1832. — Collecting vertebrate remains from continental Tertiary beds of Bad Lands south of White River, Utah. (Am. Mus. Nat. History.)

entirely lacking throughout this region. The strata are not contemporaneous in the different intermontane basins, which suggests that they did not come into existence at the same time. The principal basins and their deposits are from the south northward:

1. The San Juan Basin — Palæocene and Lower Eocene.

Fig. 1833. — Palisade Cañon, Nevada, cut by the Humboldt River through the Tertiary lava. Southern Pacific Railroad. (U. S. G. S.)

shells occur. Such a rock indicates peculiar conditions of deposition. It can scarcely be of deep-water origin, but may represent the deposits of a stagnant sea into which only pelagic organisms were carried. This would imply that at that time the Caribbean Basin was largely isolated. Panama then was formed of a ridge of igneous rock on which rested sands and muds with marine

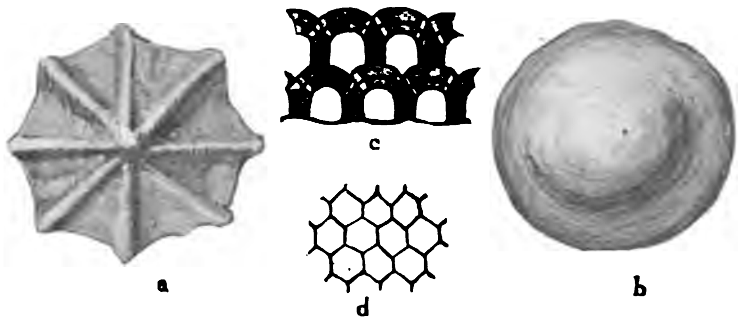


FIG. 1823. — Characteristic types of orbitoid Foraminifera from the Gulf coast and Antillean region of North America. *a*, *Orbitoides* (*Orthophragmina*), a stellately-marked form, with elongate rectangular lateral chambers. Oligocene. *b–d*. *Orbitoides* (*Lepidocyclina*) *mantelli*, outline and a few of the small cells or "lateral chambers" seen in a horizontal section or worn specimen; enlarged to show their hexagonal form. Lower Oligocene. (After Cushman.)

fossils. Limestones with large Foraminifera (*Orthophragmina*, Fig. 1823 *a*) on both sides of the Isthmus represent a late Eocene or early Oligocene submergence.

In apparent accordance with the hypothesis that the Caribbean was a stagnant, enclosed body of water into which pelagic organisms were carried (somewhat like the Black Sea, but not so deep), is the fact that the oldest Tertiary deposit of northern South America (the southern margin of the old Caribbean) consists of continental clays and sands with plant remains and of higher sands with Foraminifera. Some of these beds contain petroleum, which would be the natural product of decay of organic matter in a stagnant sea. It is not impossible that the asphaltum of Trinidad dates in part, at least, from this period.

The later Oligocene beds of this basin are normally marine, as is shown by the richly fossiliferous limestones which overlie the Montpelier chalk of Jamaica. At that time the connection with

FIG. 1835. — Palæogeographic map of North America, showing the distribution of land and sea (black) in Eocene time. (Original.)

piedmont sands and gravels accumulated in the remaining portion of the old Colorado geosyncline, and these deposits range in age from Eocene to Pleistocene. In them the bad land topography of the Great Plains has been cut (Figs. 1829–1832). These continental deposits have furnished a great number and variety of bones of extinct vertebrates, some of which are illustrated in the next Chapter. Their mode of occurrence is shown in Figure 1832.

During the Miocene, the great Columbian lava flows covered the older sediments over large areas in western North America (Fig. 1833). Tuffs and lavas were, however, also formed during

FIG. 1836. — Palæogeographic map of North America, showing the distribution of land and sea (black) in Oligocene time. (Original).

other periods of the Tertiary, both before and after the Miocene, and in some regions the outbursts of volcanic material occurred at successive intervals, long enough apart to permit the growth of forest trees on the disintegrating surfaces of the older lava and ash deposits. Those of the Yellowstone region have already been referred to (p. 196, Pt. I) and some of the silicified trees, since

FIG. 1837. — Palæogeographic map of North America, showing the distribution of land and sea (black) in Miocene time. (Original.)

exposed by erosion, are shown in Fig. 1834. In the accompanying series of maps (Figs. 1835–1838) an attempt is made to present the geographic changes in North America during Tertiary time.

Fig. 1838. — Palæogeographic map of North America, showing the distribution of land and sea (black) in Pliocene time. (Original.)

The Older Tertiary Deposits of Europe, Asia, and Africa

General Geographic Conditions. — In early Tertiary time, the geography of Europe was not much different from that of late Cretaceous time (Fig. 1839). The land mass of Atlantica in western Europe had become divided into a northern or Anglo-Icelandic and a southern or Iberian mass, though at various times the latter again became united to the land-mass of central France. On the north the Fenno-Scandian land-mass lay between the North Sea channel and the Uralian channel which separated it from Asia. This channel expanded southward into the great sea which covered much of European Russia, and on the southeast was at certain times continuous with the Indian Ocean.

At two periods, at least, this Russian sea was confluent with the North Sea channel across northern Germany. The Vindelician

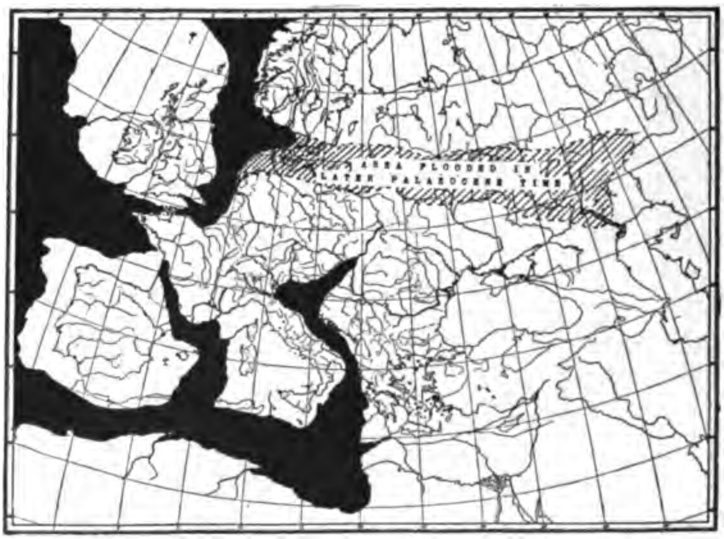


FIG. 1839. — Palæogeographic map of Europe, showing the distribution of land and sea (black) in early Palæocene time. (Original.)

land-mass still separated the northern seas from the Mediterranean, extending north and east of the present Carpathians to the Crimea and thence eastward, north of the present Caucasus Mountains. The Turkish land-mass extended into the Balkan peninsula on the one hand, and to Arabia and western India on the other. Finally, the African land-mass on the south was largely intact, the sea in Eocene time transgressing only across the Egyptian area. The main water bodies were thus the Russian Sea and the North Sea on the north, with the North German depression between; while the seas of southern Europe comprised: the Balearic or western Mediterranean (at times confluent with the Atlantic across southern Spain and across southwestern France); the main

Mediterranean Sea, extending south to Egypt and at times confluent across it with the Indian Ocean; and the Black Sea or Pontian basin and its eastward extension. Most of these seas, however, did not reach their full development until Eocene time.

Palæocene

This was a period of crustal warping, with the formation of domes and basins, but without extensive folding. The seas were

FIG. 1840. — Palæogeographic map of Europe, showing the distribution of land and sea (black) in later Palæocene time. (Original.)

very restricted at first, but later expanded (Fig. 1840). The North Sea covered northern France to Paris, Belgium, and the Netherlands, and subsequently extended into southern England (London Basin), which was then joined to France. In this basin the Lower Palæocene strata (*Montian*, named from Mons, Belgium) were laid down, these being mostly shallow-water deposits with an Arctic fauna. Practically everywhere else in Europe land existed and large parts of the Mediterranean Basin were apparently uncovered. Then an expansion of the sea took place so that Middle Palæocene strata rest disconformably upon eroded Cretaceous beds (Fig. 1848). The transgression of the sea apparently covered large areas of the North German lowland and extended to Russia. Probably a narrow channel extended from the Paris Basin to the

the Pacific was established and fossiliferous deposits (*Culebra* formation) were forming on Panama. This condition continued into the Miocene (*Gatun* formation of Panama), when richly fossiliferous deposits were formed on most of the islands of the Antilles, and when probably the continuity of the Antillean landmass had been broken, so that both the northern and southern water bodies were in intercommunication. At that time, too, the neo-Andean geosyncline, formed to the west of the young Andes Mountains, was flooded, for there Miocene strata with the Caribbean fauna, but also with Pacific and North American elements, rest directly upon metamorphic older rocks (Chile, Peru, etc.).

The oscillations of the sea in this region are shown by the fact that the early Miocene (*Bowden* marls of Jamaica, and equivalent (Chipolan) beds of southern Porto Rico) rests disconformably upon the Oligocene and is in turn disconformably succeeded by beds of Pliocene age. The Upper Miocene, represented upon the Atlantic coast by the *Chesapeake* formation, is everywhere wanting in the Antillean region and in Central America, as well as to a large extent in the Gulf coast region. This marks a great withdrawal of the waters due to elevation of the region. North and South America were joined by Central America, and the Greater Antilles were joined to one another and possibly to Central America, by the reappearance of the old land bridges from Jamaica to Honduras and from western Cuba to Yucatan, while a connection with South America along the Caribbean Arc also occurred. While this disturbance was pronounced and deformed the strata, it was not nearly so marked as the older one at the opening of Tertiary time. Matthew, however, does not think that the mammals of the Antilles bear out these connections, and it is quite possible that the land bridges were incomplete, the continued migration from South America being prohibited by open channels.

This period, too, was probably one of stagnant waters in the Caribbean, so that organic matter no doubt accumulated in the more central portions and subsequently produced the petroleum and other hydrocarbons which found their way into the adjoining porous strata. It is conditions of this kind which were probably responsible for the formation of the extensive Trinidad asphalt deposits which impregnate the Miocene rocks.

FIG. 1842. — Palæogeographic map of Asia, showing the distribution of land and sea (black) in Palæocene time. (Original.)

through them, into a residual bed which was then covered again by the transgressing sea. Thus there appears to have been a tilting of the Mediterranean Basin, resulting in a flooding on the south, in early Palæocene time, and emergence on the north; then the reverse occurred, — emergence on the south and flooding on the north in mid-Palæocene time. Finally, there was a general flooding in late Palæocene time, which was premonitory of the great flooding which took place in Eocene time.

During the Palæocene the Indian Ocean transgressed over East Africa to within about 400 miles of Cairo, but did not cover lower Egypt, for here Eocene deposits rest disconformably upon the Cretaceous. In Eocene time the Indian Ocean and Mediterranean

Sea became confluent. The Indian Ocean also transgressed over the Arabian border in Palæocene time, as is shown by deposits of this age found in that region. In the Indian peninsula, on the other hand, volcanic activities were dominant, for there the great Deccan trap-sheet was poured out over the latest Cretaceous strata. (See map, Fig. 1842.)

Owing to the wide exposure of the lands in Palæocene time, the older formations underwent much weathering, and residual deposits, such as phosphate nodules, bauxite and bog-iron ores, were extensively formed and later covered by the sediments of the encroaching Eocene Sea. This horizon is therefore of considerable economic importance.

FIG. 1843. — Palæogeographic map of Asia, showing the distribution of land and sea (black) in Eocene time. (Original.)

Eocene and Oligocene

The Eocene period witnessed a wide transgression of the sea, especially in western Asia and southern Europe. The Indian Ocean and the Mediterranean Sea became confluent across Egypt (Fig. 1843), where the first extensive marine deposit is represented by a great limestone, largely composed of the large foraminiferal shell, *Nummulites* (Figs. 1844–1845), and hence called nummulitic

Fig. 1844. — *Nummulites lævigatus* (×½), Eocene (lower Lutétian), Soissonnais, France. (After Haug.)

limestone. This rock has long been famous; it was known to Herodotus and Strabo, and was used in the building of the Great Pyramid of Gizeh (Fig. 28, p. 76, Pt. I). It rests directly upon the Cretaceous throughout northern Egypt, and many of its fossils are found in equivalent beds of the Mediterranean Basin as well as in those exposed on the border of the Indian Ocean, thus clearly indicating the continuity of these seas at that time. This continuity was again broken in late Eocene time, when the formations of north Egypt became non-marine.

Not only was the entire area of the modern Mediterranean flooded by this advance of the sea, but many parts of the bordering lands were also submerged (Fig. 1846). Probably all of Italy, except perhaps the central ridge, was covered by the sea which also extended over the areas now occupied by the Alps, the Carpathians, and the Taurus Mountains of Asia Minor, while the Black Sea flooded the region of the present Caucasus Mountains. These areas, now deformed and elevated, were then geosynclines, each lying at the foot of the landmass from which the sediments were derived. Those of the Alps were brought by rivers from the oldland of France on the west and from the Vindelician land on the north. Those of the Carpathians were derived from the old pre-Carpathian arc of land, which was a continuation of the Vindelician land and enclosed the Hungarian or *Pannonian* Basin on three sides.

Fig. 1845. — Piece of nummulitic limestone from the Pyrenees, showing sections of shells; natural size. Eocene.

Fig. 1846. — Palæogeographic map of Europe, showing the distribution of land and sea (black) in Eocene time. (Original.)

The sediments of the Taurus and Caucasus geosynclines came from lands on their northern borders. In nearly all of these geosynclines the sands and muds accumulated in very shallow water or actually above sea-level, forming a clastic rock with few fossils, known as *Flysch*. This type of deposit has a thickness of several thousand feet, and continues into the Oligocene, forming one of the characteristic early Tertiary rock types. In some sections, as in the Carpathian geosyncline, local lagoonal

FIG. 1847. — Palæogeographic map of Europe, showing the distribution of land and sea (black) in mid-Oligocene time. (Original.)

conditions were established, and salt deposits were formed. Elsewhere, in Hungary, in Italy, in southwestern France, etc., normal marine deposits accumulated, in which nummulites played an important part as limestone-makers. Toward the end of Eocene time a partial retreat of the sea set in, followed by a readvance in the Oligocene, which was especially marked in mid-Oligocene time (Fig. 1847). Fresh-water (river) deposits also became prominent in the Oligocene, especially in the Balearic or Western Mediterranean Basin, where, during the mid-Oligocene expansion of the sea, extensive gypsum and salt deposits were formed, some of them carrying potash salts.

In mid-Oligocene time the sea also filled a trough-like depression situated where to-day is found the Rhine Valley, and this channel connected the Mediterranean Sea with that which covered northern Europe. Later this channel was closed on the north by a rise of the land, and the waters, by evaporation, gave rise to the salt and finally the potash deposits of Alsace.

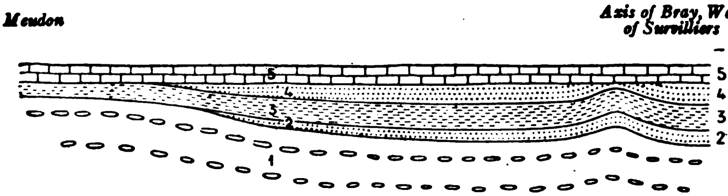


FIG. 1848. — Restored cross-section showing the Eocene strata from the Meudon dome to the Axis of Bray. (After Munier-Chalmas.)

1, Senonian chalk (Upper Cretaceous); 2, Thanetian beds (Palæocene); 3, clay and lignites (lower Londinian, Upper Palæocene); 4, Cuise sandstones (upper Londinian, Upper Palæocene); coarse, fossiliferous limestone (Calcaire Grossier, Eocene).

In northern Europe the best known and most important Eocene deposits are those of the Paris Basin. They rest upon erosion remnants of the Palæocene, or by overlap upon the Upper Cre-

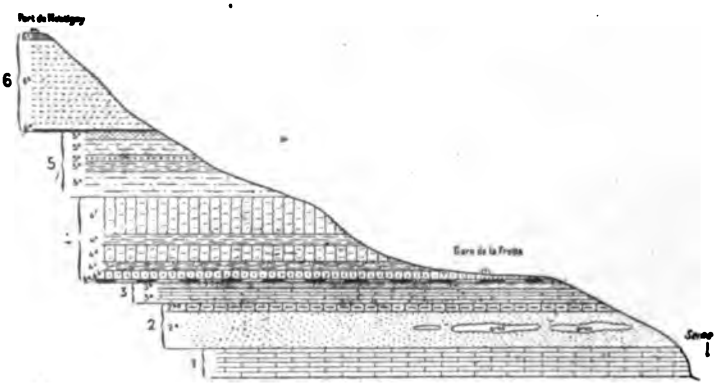


FIG. 1849. — Section of the coasts of Frette and Montigny, Seine-et-Oise, France. (After Vasseur and Carez.)

1, Upper Lutétian (Eocene); 2, Auversian (Middle Eocene); 3, Bartonian; 4, Ludian (Upper Eocene); 5, Lattorfian (Lower Oligocene); 6, Rupélian (Middle Oligocene).

taceous (Fig. 1848), and consist of limestones and calcareous sands, filled with molluscan shells, the abundance and perfection of which have made this region famous (Figs. 1877, 1881 *a*). Toward the end of early Eocene time, however, the waters freshened so that

FIG. 1830. — Bluff of "Protoceras sandstones" in the Bad Land region of South Dakota. Continental Upper Oligocene. (U. S. G. S., courtesy *Popular Science Monthly*.)

FIG. 1831. — Erosion remnants ("Teapot and cup") of finely laminated Green River shales capped by hard brown sandstone. Upper Palæocene. Wyoming. (U. S. G. S.).

sum was deposited. This continued, with occasional incursions of the sea into the basin and temporary restoration of the conditions under which normal marine animals could live, until a total of 25 meters or more of gypsum was deposited. These gypsum beds are extensively quarried in and near Paris (Fig. 1850) and have become famous, for from them were obtained the skeletons of mammals and other vertebrates from which the naturalist Cuvier (portrait, Fig. 6, p. 24) was able to restore a part of the remarkable life-record of this period and lay the foundation not only of comparative anatomy but also of vertebrate palæontology. The lagoon which occupied the Paris region and in which the gypsum was formed was about half the size of the Karabugas Gulf (Pt. I, p. 239, Fig. 169), but like it in practically all respects. Drought

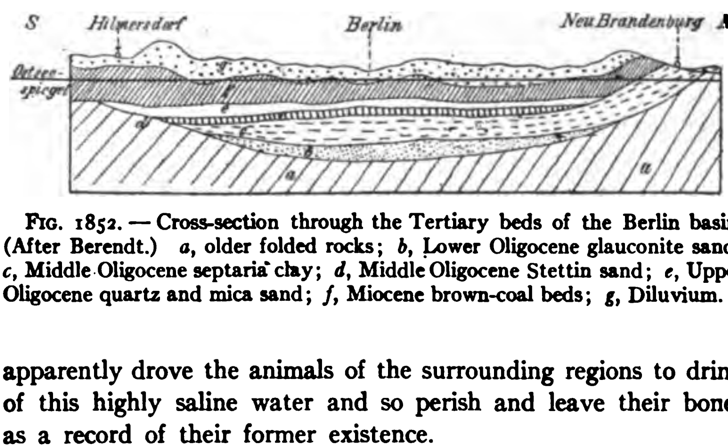


FIG. 1852. — Cross-section through the Tertiary beds of the Berlin basin. (After Berendt.) *a*, older folded rocks; *b*, Lower Oligocene glauconite sand; *c*, Middle Oligocene septaria clay; *d*, Middle Oligocene Stettin sand; *e*, Upper Oligocene quartz and mica sand; *f*, Miocene brown-coal beds; *g*, Diluvium.

apparently drove the animals of the surrounding regions to drink of this highly saline water and so perish and leave their bones as a record of their former existence.

The North Sea expansion also covered the Netherlands and the North German lowlands as far east as Berlin, while much of Poland and Russia was likewise covered by marine waters. In mid-Oligocene time (map, Fig. 1847) these two water bodies became confluent, extending across northern Europe from eastern England to the Ural Mountains and beyond, covering in many places deposits of lignite and brown-coal which had been formed on this lowland plain in early Oligocene time (Fig. 1851), and covering also the fresh-water limestones and sands which followed upon the gypsum beds of the Paris Basin. These marine conditions continued with some oscillations to the end of the Oligocene (Fig. 1852).

THE LATER TERTIARY OR NEOGENE OF EUROPE, ASIA, AND AFRICA

The Neogene includes the *Miocene* and *Pliocene* deposits. The period opened with the formation of the principal mountain ranges of modern Europe, though these were further accentuated in subsequent time. These mountain ranges, which include the Alps, the Carpathians, the Caucasus, and others, were formed by the folding of the strata of the geosynclines of the preceding periods, while behind these mountains upon the oldland which had supplied

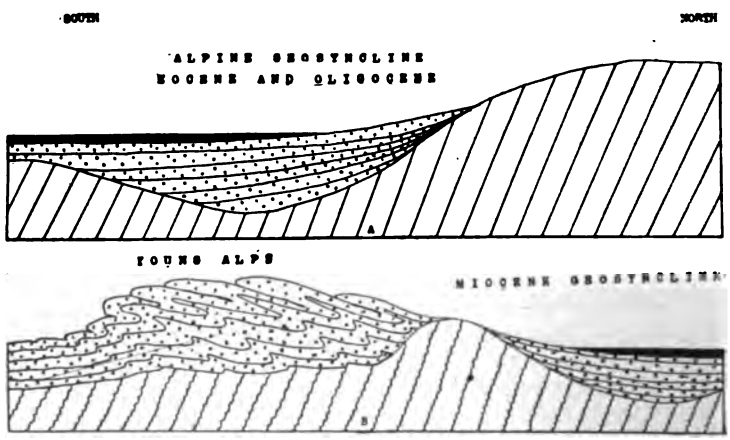


FIG. 1853. — Diagrammatic sections illustrating the conditions in the region of the modern Alps: (*A*) in Eocene and Oligocene time, when the strata chiefly involved in the Alpine folds were deposited in the Alpine geosyncline, and (*B*) the conditions after the early Miocene folding, and the formation of the new geosyncline, in which the younger Tertiary beds were deposited. (Original.)

the sediments for the deposits in the geosynclines, a new series of geosynclines came into existence, one for each mountain system. In these new depressions the later Tertiary strata were deposited, formed from sediments largely derived by the erosion of the new mountains. Thus a trough extended parallel to the Alps through France (Rhone Valley) and southern Germany (Fig. 1853). In this trough the Miocene and younger deposits were partly marine and partly fresh-water. A second trough ran parallel to the new Carpathians on the east and north, and there, besides marine embayments in which reef-forming Bryozoa flourished (Fig. 1854), were many lagoons in which great salt beds, some of them

FIG. 1835. — Palæogeographic map of North America, showing the distribution of land and sea (black) in Eocene time. (Original.)

piedmont sands and gravels accumulated in the remaining portion of the old Colorado geosyncline, and these deposits range in age from Eocene to Pleistocene. In them the bad land topography of the Great Plains has been cut (Figs. 1829–1832). These continental deposits have furnished a great number and variety of bones of extinct vertebrates, some of which are illustrated in the next Chapter. Their mode of occurrence is shown in Figure 1832.

best known of which is in the region around Vienna (Fig. 1856). Continental, and mixed continental and marine deposits also accumulated there wherever high land-masses furnished much sediment.

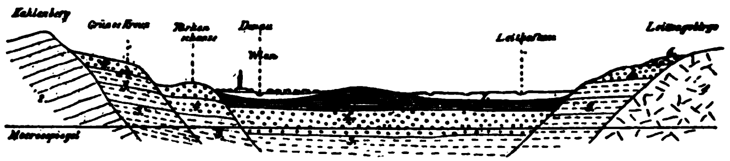


FIG. 1856. — Schematic cross-section through the Tertiary Basin of Vienna. 1, Crystalline rocks of the Leithagebirge; 2, Flysch of the Wiener Wald; 3, marine Miocene (Mediterranean stage); 4, brackish Upper Miocene (Sarmatian stage); 5, *Congeria* beds; 6, Belvedere gravels; 7, Diluvium and Alluvium. (After Karrer.)

At that time most of northern Europe had become dry land, the great Oligocene seas which had covered it having withdrawn. Only the North Sea stretched south from the Arctic, much as it does to-day, covering parts of Belgium and the Netherlands but not France. England and France were still joined, but the Atlantic penetrated part way into western France, extending at one time as far as Tours and Blois on the north and for some distance into Aquitania on the southwest, as shown by the marine strata in those regions. Elsewhere upon the dry land, river and other continental sediments were forming, and these enclosed the remains of the mammals and other land-animals of the period.

FIG. 1857. — *Congeria subglobosa.* Pontian (Upper Miocene) near Mödling, Lower Austria. (After Partsch from Haug.)

The Indian Ocean transgressed in Miocene time over the African coastal region and northward far into Persia and northeastern Turkey, almost to the Black and Caspian Seas, which were, however, distinct and a part of the European system of waters. Extensive deposits of limestone and other sediments, called the *Supra-nummulitic* formations, were deposited in those seas. The final evaporation of the waters gave rise to great salt and gypsum beds in Persia, Armenia, and the Trans-Indus region, including probably those of the Salt Range which were at one time thought to be of pre-Cambrian age, because Cambrian strata rest upon them, apparently by overthrust. Great fluviatile formations also were accumulating at that time in northern India, and they enclose the remains of vertebrates.

Fig. 1858. — Palæogeographic map of Europe, showing the distribution of land and sea (black) in Pliocene time. (Original.)

In late Miocene time the seas became much more restricted in Europe, and the expanded Caspian and Black Sea basins became brackish water bodies, in which the pelecypod *Congeria* (Fig. 1857) was especially abundant. This continued into Pliocene time (Fig. 1858), while over the Hungarian Basin extensive fresh-water lakes had come into existence. The Apennines had begun to rise, but the greater part of Italy was submerged beneath the waters of the Mediterranean, and there we find some of the best marine Pliocene deposits. The latest of these, the *Sicilian* (Fig. 1859), is by some referred to the Lower Quaternary. The coastal lands of France and Spain were also more or less submerged.

It was at that period that the Straits of Gibraltar first came into existence, so that Spain broke away from Morocco, with which it was united up to that time (Fig. 1642, p. 666). The Straits of Dover, on the other hand, did not open until much later, England and France still being joined by a land bridge. The North Sea still

FIG. 1859. — Conglomeratic sandstone of the Pliocene (Sicilian) of Ficarazzi, near Palermo, Italy, with *Cyprina islandica*, *Dosinia lineata*, *Pecten subclavatus*, *Pecten opercularis*, etc. (×⅔). (After Haug.)

covered some of the coastal lands including southeastern England, but so far as we know the Baltic Sea had not yet come into existence. As in other periods, continental deposits accumulated on many parts of the lands, and they included the remains of the land animals and plants of the time.

Neither the Indian nor the Pacific oceans transgressed far over the Asiatic lands in Pliocene time, but thick continental deposits formed at that period in many parts of Asia.

the latter again became united to the land-mass of central France. On the north the Fenno-Scandian land-mass lay between the North Sea channel and the Uralian channel which separated it from Asia. This channel expanded southward into the great sea which covered much of European Russia, and on the southeast was at certain times continuous with the Indian Ocean.

At two periods, at least, this Russian sea was confluent with the North Sea channel across northern Germany. The Vindelician

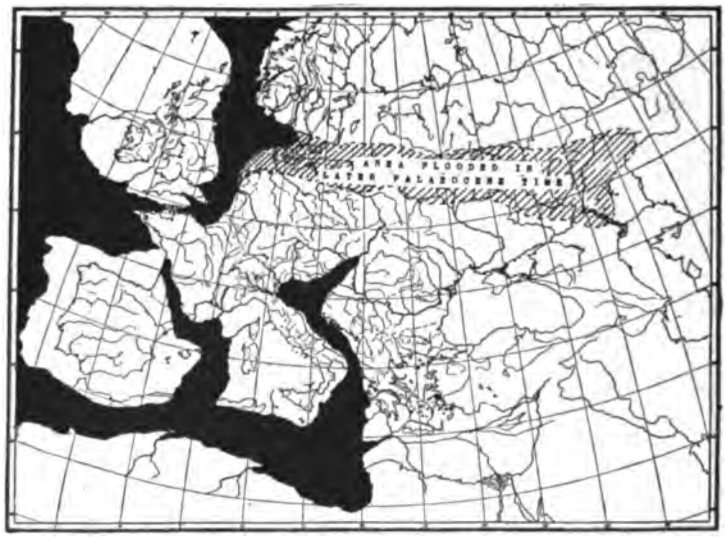


FIG. 1839. — Palæogeographic map of Europe, showing the distribution of land and sea (black) in early Palæocene time. (Original.)

land-mass still separated the northern seas from the Mediterranean, extending north and east of the present Carpathians to the Crimea and thence eastward, north of the present Caucasus Mountains. The Turkish land-mass extended into the Balkan peninsula on the one hand, and to Arabia and western India on the other. Finally, the African land-mass on the south was largely intact, the sea in Eocene time transgressing only across the Egyptian area. The main water bodies were thus the Russian Sea and the North Sea on the north, with the North German depression between; while the seas of southern Europe comprised: the Balearic or western Mediterranean (at times confluent with the Atlantic across southern Spain and across southwestern France); the main fine, round or hexagonal (*Lepidocyclina*, Fig. 1823 *b–d*) or quadrangular (*Orthophragmina*, Fig. 1823 *a*) chambers, reinforced on each side by similar layers of concentrically arranged cells. Other

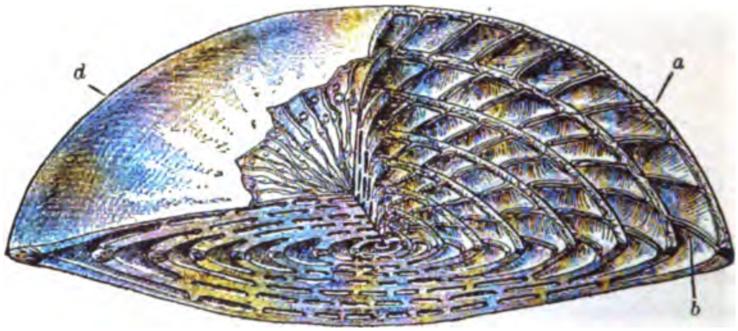


Fig. 1861. — *Nummulites* cf. *lucasanus*, partly sectioned; *a*, outer or dorsal margin; *b*, septa; *d*, wall. Eocene of Kressemberg. Enlarged several times. (From Bernard.)

common Foraminifera, mostly, however, with greater ranges, are *Miliola* (*Biloculina* (Fig. 1863), *Triloculina*, *Spiroloculina* (Fig. 1864), *Quinqueloculina*), the discoid *Orbitolites*, the elongate

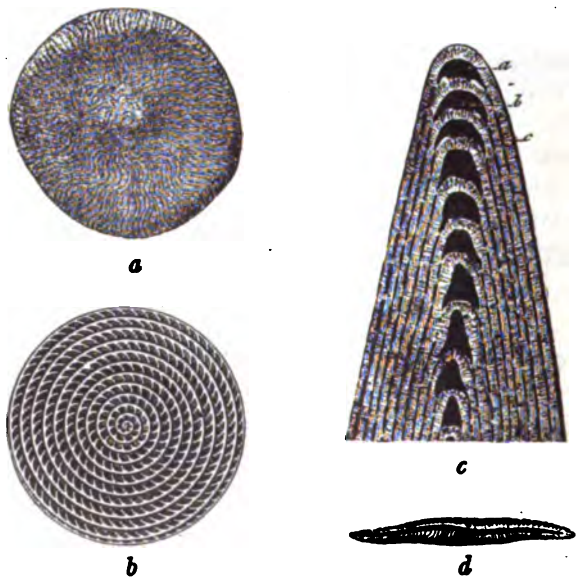


Fig. 1862. — *Nummulites nummularia*. *a*, external view; *b*, horizontal section; *c*, transverse section, much enlarged; *d*, side view. (After d'Orbigny.)

Aveolina, which resembles *Fusulina* of the Palæozoic and is especially characteristic of the European Tertiary, where it is often rock-forming. Among other forms are the disk-shaped *Amphistegina* (Fig. 1865) and the few-whorled, flat *Operculina*

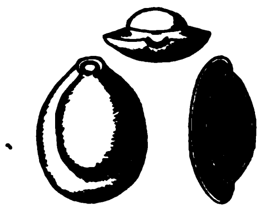


FIG. 1863. — *Biloculina inordinata*, Miocene, Baden. Two views and section; enlarged.

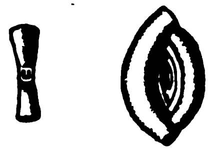


FIG. 1864. — *Spiroloculina badensis*, a Miocene foraminiferal shell from Baden, two views. (Haas' *Leitfossilien*.)

FIG. 1865. — *Amphistegina lessoni*. *A*, *B*, opposite views; *C*, section (*a*, apertures; *b*, solid axial mass). A characteristic Miocene foraminifer (Leithakalk, Vienna), enlarged eight diameters. (After Steinmann.)

FIG. 1866. — *Turbinolia sulcata*, side and calicular view, much enlarged. (After d'Orbigny.)

FIG. 1867. — *Endopachus maclurii*, Eocene. (After d'Orbigny.)

and *Heterostegina*, which appear like minute, laterally compressed nautiloid shells. These types are as a rule sufficient to identify Tertiary strata.

Corals. — Some of the characteristic simple types are ***Turbinolia*** (Fig. 1866), ***Flabellum*** (Fig. 1868 *c, d*), ***Platytrochus*** (Fig. 1868 ***a, b***),

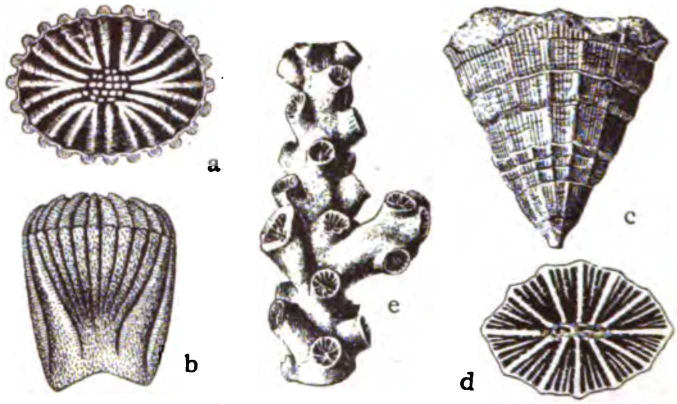


FIG. 1868. — Tertiary corals. *a, b, **Platytrochus stokesi.*** much enlarged, Eocene (Claiborne); *c, **Flabellum cuneiforme,*** side view; *d, **F. lerchi,*** calyx, Eocene to Oligocene (Claiborne, Jackson, Vicksburg); *e, **Oculina mississippiensis,*** Oligocene (Vicksburg). (I. F.)

and *Endopachus* (Fig. 1867), besides many others. The compound corals are mostly of genera still living, though usually of distinct species. (*Oculina*, Fig. 1868 *e*; *Septastræa*, Fig. 1869 *a*), etc.

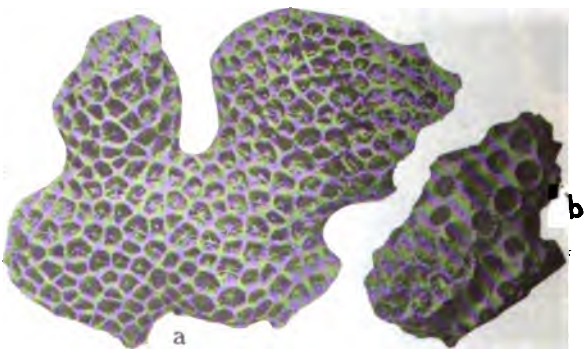


FIG. 1869. — Compound corals of the Tertiary. *a, **Septastræa marylandica,*** Upper Miocene (St. Mary's); *b, **Astrohelia palmata,*** Miocene. (I. F.)

Brachiopods are rare, *Terebratula* alone being widespread (Fig. 1870).

Pelecypods. — This class is abundantly represented, but the genera are mainly modern ones. Among them may be cited for

FIG. 1870. — *Terebratula grandis* ($\times \frac{3}{4}$), a characteristic Oligocene brachiopod.

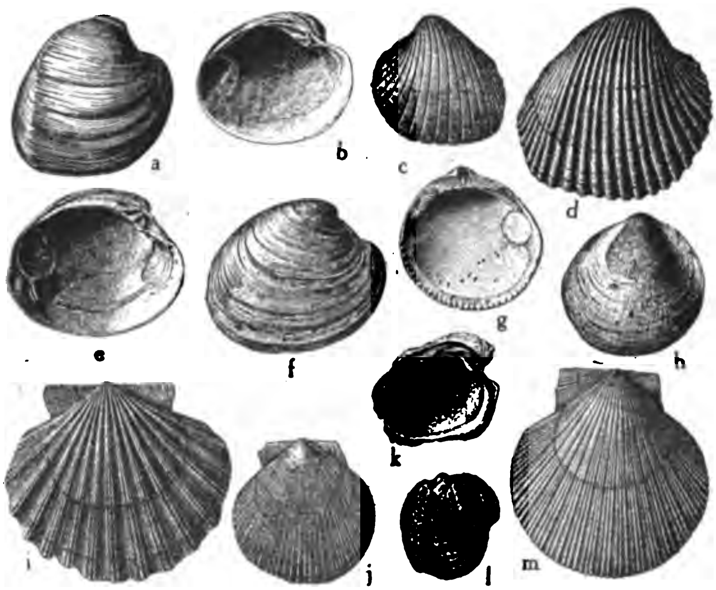


FIG. 1871. — Tertiary pelecypods. *a*, *b*, *Isocardia fraterna* ($\times \frac{1}{3}$), exterior and interior views, Miocene; *c*, *Venericardia planicosta*, left valve ($\times \frac{1}{2}$), Eocene; *d*, *V. smithi*, right valve ($\times \frac{1}{2}$), Eocene; *e*, *f*, *Venus mercenaria*, interior and exterior views ($\times \frac{1}{4}$), Miocene to recent; *g*, *h*, *Glycimeris idonea*, interior and exterior views ($\times \frac{1}{3}$), Eocene; *i*, *Pecten madisonius*, left valve ($\times \frac{1}{4}$), Miocene; *j*, *P. choctavensis*, left valve ($\times \frac{3}{4}$), Eocene; *k*, *l*, *Chama congregata*, interior of left, exterior of right valves ($\times \frac{1}{2}$), Miocene to recent; *m*, *Pecten marylandicus*, left valve ($\times \frac{1}{2}$), Miocene. (I. F.)

their frequency, *Pecten* (Fig. 1871 *i, j*), *Glycimeris* (Fig. 1871 *g, h*), *Arca*, *Venericardia* (Fig. 1871 *c, d*), *Venus* (Fig. 1871 *e, f*), *Cytherea*, *Chama* (Fig. 1871 *k, l*), *Cardium*, and *Congeria* (Figs. 1857, 1873).

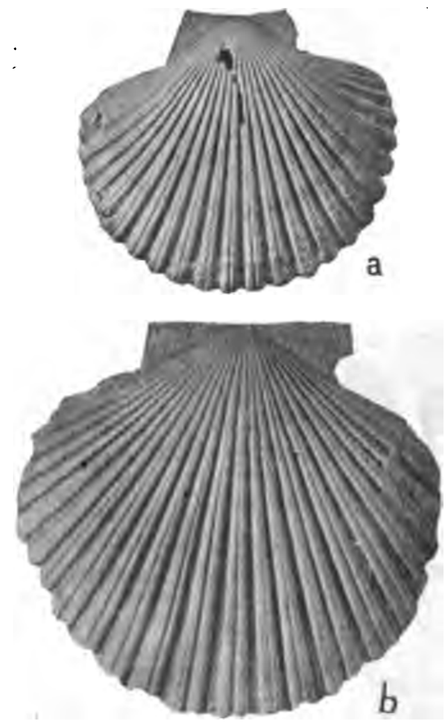


FIG. 1872. — Pliocene Pectens of California. *a*, *Pecten stearnsii*; *b*, *P.* (*Patinopecten*) *healeyi* (both × ½). (I. F.)

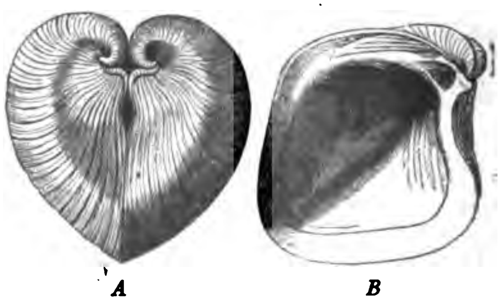


FIG. 1873. — *Congeria conglobata* (about ½ natural size). *A*, anterior view showing twisted beaks; *B*, interior of left valve. Pliocene of Europe.

Gastropods are equally numerous and characteristic, though again modern genera predominate. Mention may be made for their frequency of *Turritella* (Fig. 1874), *Cerithium* (Figs. 1875,

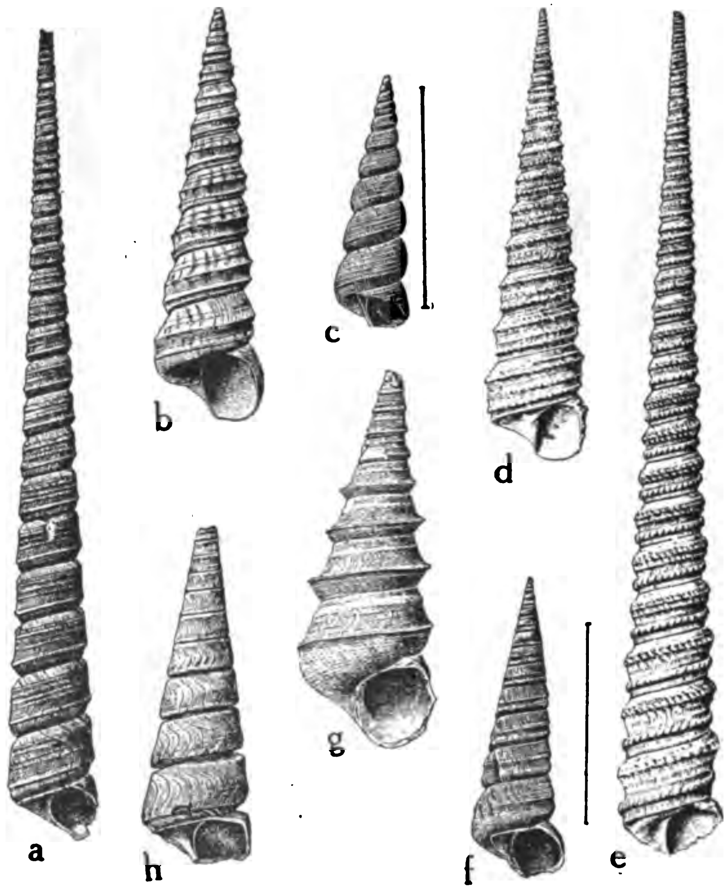


FIG. 1874.—Tertiary Turritellas. *a*, ***Turritella cumberlandia*** ($\times\frac{3}{4}$), Miocene; *b*, *T. subannulata* ($\times 1\frac{3}{4}$), Oligocene-Pliocene; *c*, *T. plebeia* ($\times\frac{3}{4}$), Miocene; *d*, *T. apicalis* ($\times 1\frac{1}{2}$), Pliocene; *e*, *T. perattenuata* ($\times\frac{3}{4}$), Pliocene; *f*, *T. æquistriata* ($\times\frac{3}{4}$), Miocene; *g*, *T. mortoni* ($\times\frac{1}{2}$), Eocene; *h*, *T. indenta* ($\times\frac{3}{4}$), Oligocene-Miocene. (I. F.)

1876), *Fusus* (Figs. 1877, 1878), *Clavilithes* (Figs. 1880, 1881 *a*), *Pyrula* (Fig. 1881 *c*), *Sycotypus* (Fig. 1882), *Volutilithes* (Fig. 1883 *d*, *e*), *Pleurotoma* (Figs. 1883 *g*, 1884 *a*), *Ecphora*, and others. Also the fresh-water forms *Paludina* (*Vivipara*) (Fig. 1885),

FIG. 1875.—*Cerithium serratum*, Eocene.

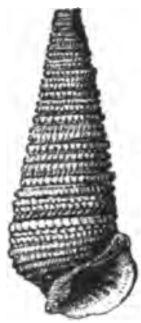


FIG. 1876.—*Cerithium margaritaceum*, Oligocene.

FIG. 1877. — *Fusus longirostris*, Miocene.

FIG. 1878.—*Fusus asper* ($\times \frac{8}{3}$) with apical portion further enlarged ($\times$ 10). A characteristic Eocene shell of the Paris and London basins.

FIG. 1879. — *Falsifusus meyeri*, Eocene. Gulf Coast of North America.

FIG. 1880. — *Clavilithes solanderi*, a gerontic individual, one-half natural size; Eocene. London Basin. (After Sowerby.)

FIG. 1881 *a*.— *Clavilithes parisiensis*, Eocene. Paris Basin. (Reduced.)

FIG. 1881 *b*. — *Leiostoma bulbiformis*, Eocene. (Reduced.)

FIG. 1881 *c*. — *Pyrula rusticula*, Miocene.

FIG. 1881 *d*. — *Ficula reticulata*, Miocene.

FIG. 1882. — *Sycotypus rugosus*, Miocene. One-half natural size. Atlantic Coast of America.

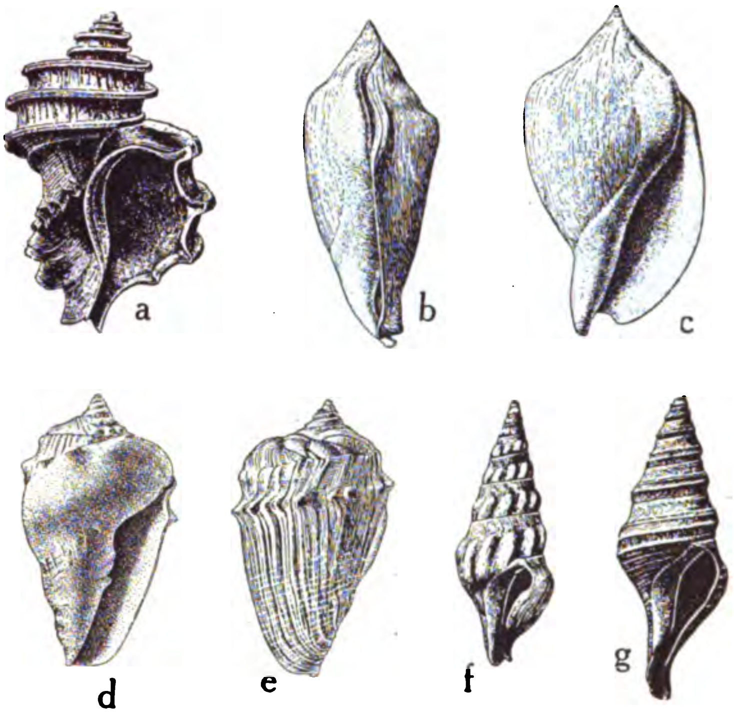


FIG. 1883. — American Tertiary gastropods. *a*, *Ecphora tricostata* ($\times \frac{3}{4}$), Miocene; *b*, *c*, *Orthaulax gabbi* ($\times \frac{1}{2}$), Oligocene-Miocene; *d*, *e*, *Volutilithes petrosus* ($\times \frac{3}{4}$), Eocene; *f*, *Drillia limatula* ($\times 1$), Miocene; *g*, *Pleurotoma biscatenaria* ($\times 1$), Miocene. (I. F.)

FIG. 1884 *a*.— *Pleurotoma cataphracta*, Miocene.

FIG. 1884 *b*. — *Melania escheri*, Miocene.

Physa, and *Planorbis* (Fig. 1886). **Cephalopods** are rare and are represented chiefly by *Nautiloids* with lobed sutures (*Aturia*, Fig. 1887).

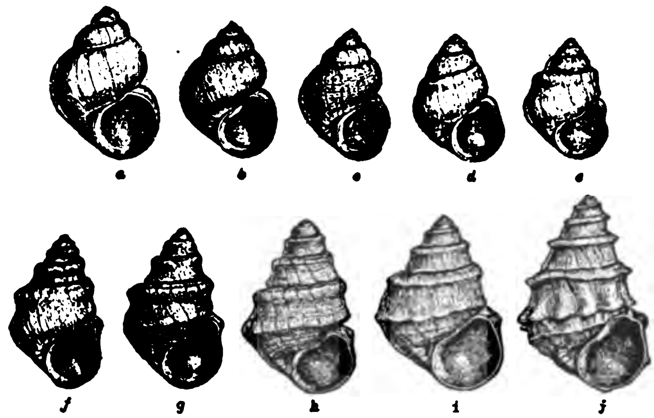


FIG. 1885. — Series of *Paludinas* (*Vivipara*) from the Lower Pliocene deposits of Slavonia. *a*, *Paludina neumayri*; *k*, *P.* (*Tulotoma*) *hoernesi* from the highest beds; *b-i*, intermediate forms, showing gradation, from the intermediate beds. (After Neumayr.)

Among the **Crustacea** the crabs or brachyurian decapods are abundant (Fig. 1888). **Insects** are numerous and of modern type. Famous insect-bearing formations are the Oligocene amber of the Baltic and the Lower Miocene lake beds of Florissant, Colorado

FIG. 1886. — *Planorbis multiformis*, a very variable fresh-water gastropod from the Upper Miocene sands of Steinheim in Württemberg. (Enlarged.)

(Fig. 1889). **Echinoids** are abundant but chiefly of the irregular types, common genera being *Linthia*, *Maretia*, *Conoclypeus* (Fig. 1890), and *Echinolampas* (Fig. 1891) of the older, and *Scutella* and *Clypeaster* (Figs. 1892, 1893) of the younger Tertiary.

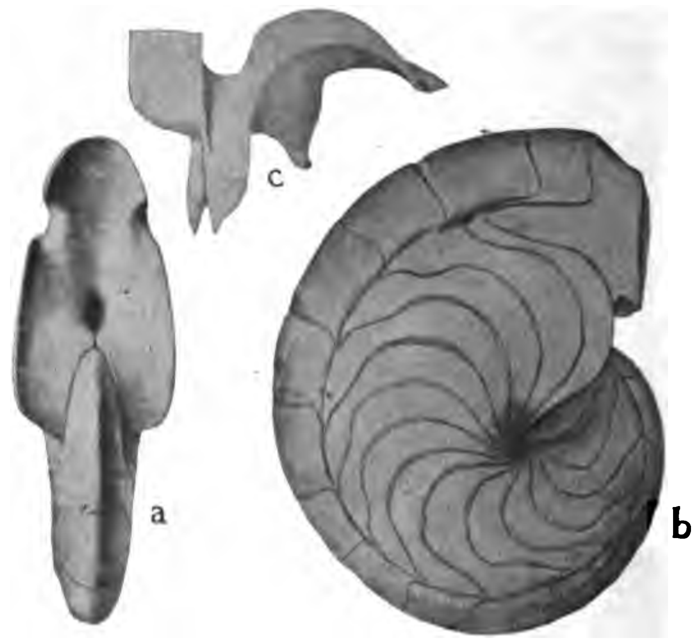


FIG. 1887. — A Tertiary nautiloid, *Aturia vanuxemi* ($\times \frac{5}{12}$), Eocene. *a-b*, front and lateral views; *c*, rock filling between two septa, showing the lobes of the suture, and the funnel-form siphuncle. (I. F.)

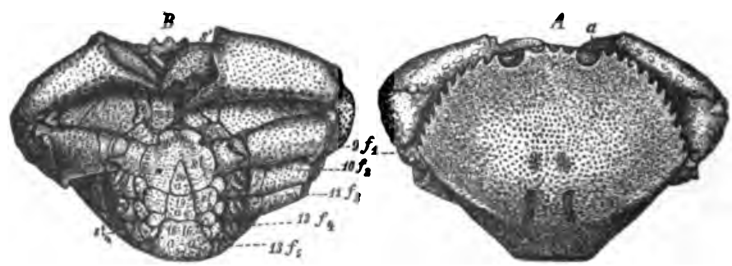


FIG. 1888.—*Harpactocarcinus punctulatus*, Eocene; Vicentin male. *A*, dorsal, *B*, ventral aspect. *a*, eye sockets; *r*, rostrum; 8–20, segments of body; *mx*, maxillæ; f_1, first pair of thoracic legs with chelæ (pincers) *s*, *s'*; f_2–f_5, second to fifth pair of thoracic legs; a_1–a_7, abdominal segments; st_1–st_4, sternites. One-third natural size. (After Steinmann.)

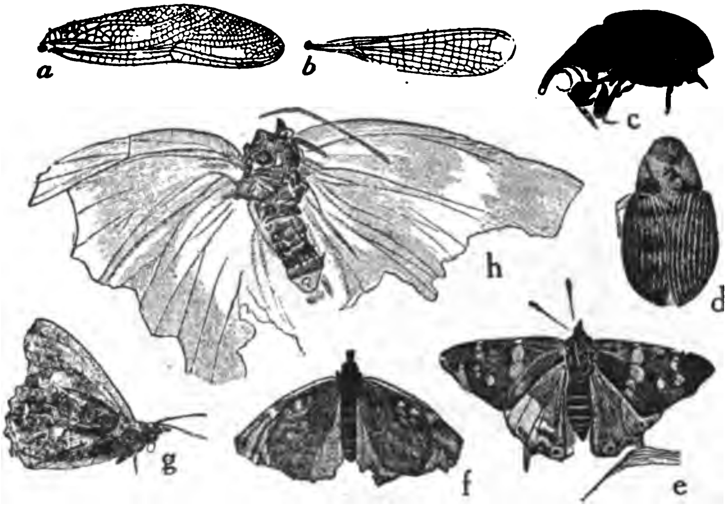


FIG. 1889.—Tertiary Insects from the extinct Oligocene lake of Florissant, Colorado. *a, b*, **Odonata** or dragon-flies (*a, Stenogomphus carletoni*, left fore-wing (×⅞); *b, Trichocnemis aliena*, right wing (×2); *c, d*, **Coleoptera** or beetles (*c, Acalyptus obtusus* (×9); *d, Cryptorrhynchus profusus* (×9); both from the Florissant beds); *e–h*, **Lepidoptera** or butterflies and moths (*e, Prodryas persephone* (×⅞); *f, Jupiteria charon* (×⅞); *g, Barbarothea florissanti* (×⅞); *h, Nymphalites obscurus* (×1½). (I. F.)

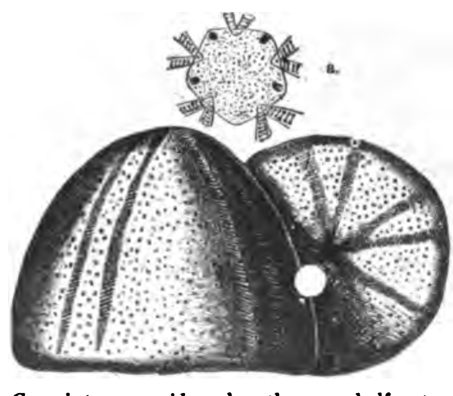


FIG. 1890. — *Conoclypeus conoideus*, less than one-half natural size. Eocene (nummulitic limestone). *a*, enlarged madreporic body with four genital pores.

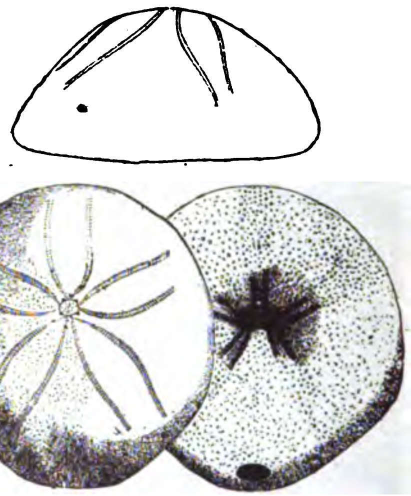


FIG. 1891. — *Echinolampas kleini* (×$\frac{2}{3}$). Oligocene.

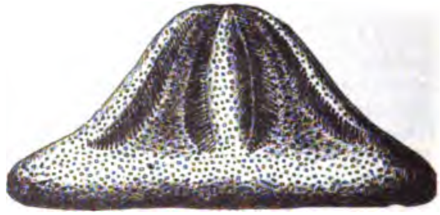


FIG. 1892. — *Clypeaster altecostatus* (×$\frac{2}{3}$). Miocene.

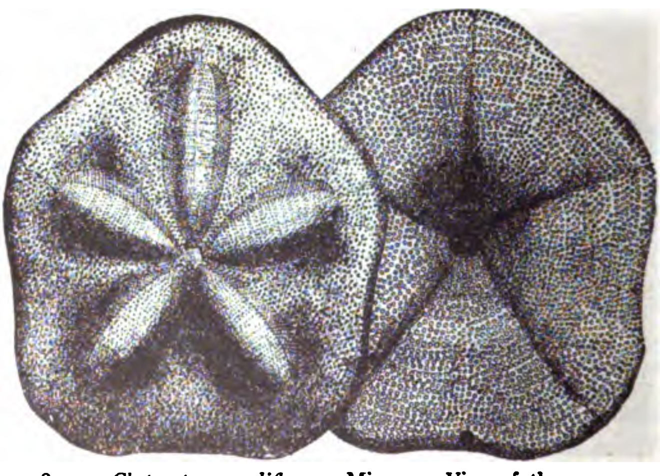
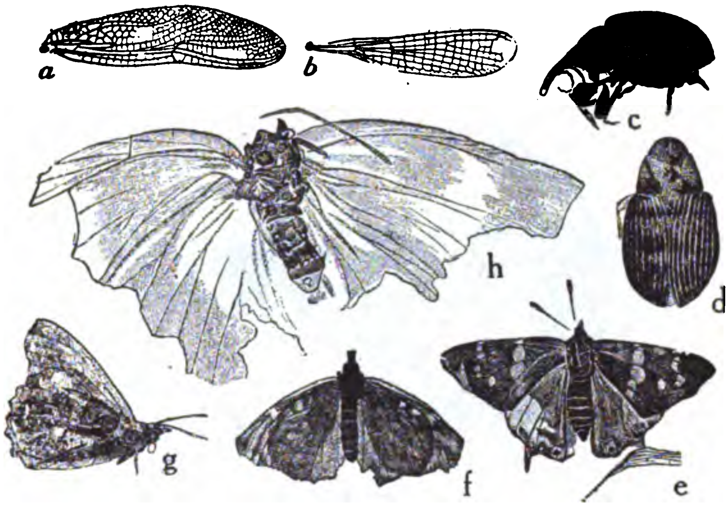


FIG. 1893. — *Clypeaster grandiflorus*. Miocene. View of the upper surface denuded of the spines, showing the petal-form ambulacra, and view of lower surface, showing food grooves and marginal anal opening. (After Desor.)



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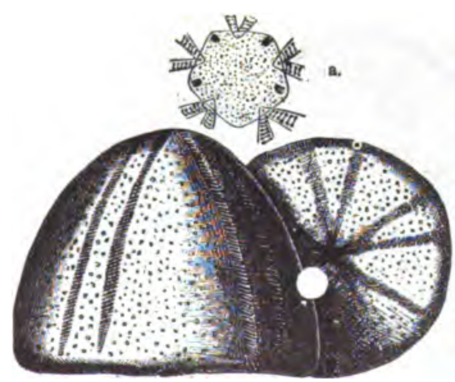

FIG. 1890. — *Conoclypeus conoideus*, less than one-half natural size. Eocene (nummulitic limestone). *a*, enlarged madreporic body with four genital pores.

other reptiles. There were, of course, many genera which are not represented by modern species. Of those genera which are still extant, the species were, as a rule, distinct in Tertiary time, but the distinctions are mostly such as only a specialist can recognize. Remains of birds have also been found, but by far the most characteristic animals of the Tertiary were the mammals. To these we shall devote the remainder of this chapter.

The Mammals of the Tertiary

The Archaic Mammals

The dawn of Tertiary time reveals the presence upon our earth of mammals which had already become highly specialized and adapted to various habitats, though in their structure they retained many primitive characters. These were the archaic mammals with extremely small brains, simple, triangular teeth, five-toed feet, and flat-footed (plantigrade) mode of progression. They were defective in mental power, ill adapted in tooth-structure for the effective procurement of food, and in general not well fitted for rapid motion, because of their flat-footedness. In other respects, however, they had become very diverse, simulating the structural characters which, in the higher types, characterize the different groups. There were forms resembling bears, cats, hyænas, rodents, etc., but these were not ancestral to the types they resembled, developing rather along parallel structure lines. It appears that they represent the first attempt of nature to develop insect-eating, flesh-eating, and plant-eating mammals, animals with claws, and animals with hoofs, but this attempt was unsuccessful, because other structures were not developed to a similar degree. They thus represent one of nature's failures, specialization on an insufficient foundation, and it is probable that the entire group disappeared, though some of the peculiar primitive mammals of Australia and America may be the descendants of these early types preserved to-day in specially favorable "asylums." Such are the egg-laying *Echidna* and Duckbill, the pouched marsupials, (the Australian kangaroo and the American opossum), the insectivores, which are, however, already very modern in structure and among which the hedgehogs, moles, and shrews may be mentioned, and the edentates, such as the ant-eaters, sloths, and armadillos of South America, some of which extend as far north as the Southern States.

The Lower Vertebrates

Under this head we shall note the fishes, amphibians, reptiles, and birds.

Sharks were abundant, and their teeth form a characteristic feature of most marine Tertiary deposits. They are often large, up to 6½ inches long, and if we judge by the relative size of teeth and length of body of modern sharks, such a form must have been 70 or 80 feet in length, with jaws five or six feet in width. Bony fishes (teleosts) abounded in both fresh and salt water, beautifully preserved specimens being found in the Green River (Palæocene) shales of Wyoming (Fig. 1894) and the Tertiary beds of Mt. Lebanon. Amphibians were represented by close relatives of the existing types, and so were the snakes, turtles (Fig. 1895), and

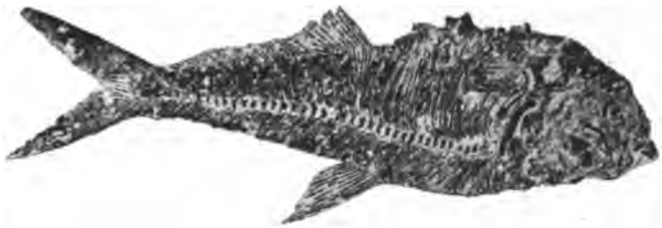

Fig. 1894. — A fossil fish (*Diplomystus dentatus*) from the finely laminated clays of the Green River formation (Upper Palæocene) in Wyoming. (U. S. G. S.)

Fig. 1895. — Opposite sides of the shield of a Palæocene turtle, *Hoplochelys elongata*, from the Torrejon formation of San Juan County, New Mexico. (After Gilmore.)

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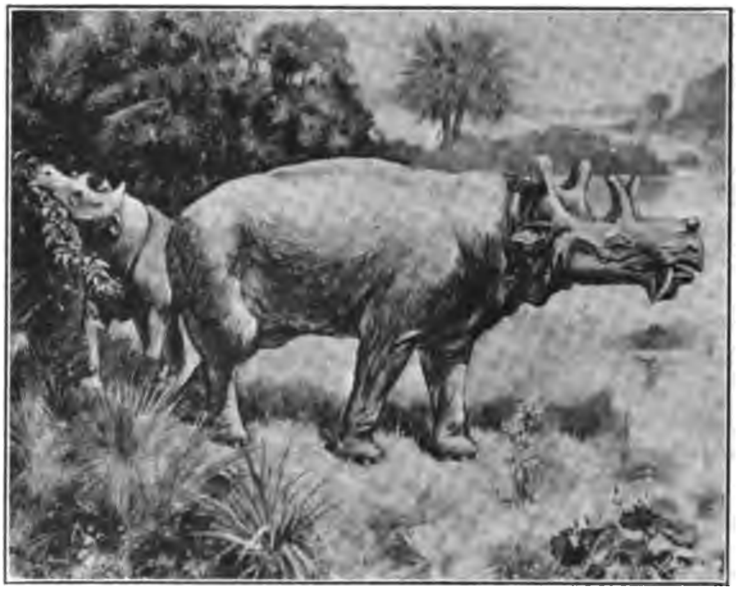

FIG. 1898. — Restoration of a primitive four-horned, hoofed mammal (*Eobasileus*), the last of the race of amblypods or heavy-limbed, archaic mammals. They were characteristic of, and confined to, the Eocene, *Eobasileus* surviving to the Upper Eocene. To the right, a male with large horns and tusks; to the left, a female with small horns and tusks. (Courtesy of American Museum of Natural History.)

and their descendants migrated northward and mingled with the animals of northern origin. From the north apparently came the flesh-eaters or carnivores, the gnawers or rodents (mice, rats, squirrels), the lemurs, the odd-toed ungulates or perissodactyla (horses, tapirs, rhinoceros), the even-toed ungulates or artiodactyla (pigs, camels, deer, giraffes, antelopes, sheep, cattle, etc.) and others. Africa appears to have been the original home of the mastodons and elephants, and of some of the aquatic mammals such as sea-cows, dugongs, primitive whales, etc. In South America finally arose the opossums, ant-eaters, sloths, and armadillos, some of which penetrated to North America in Tertiary or early Quaternary time. Two periods of migration between South and North America are recognized — the Palæocene or basal Eocene (also perhaps late Cretaceous) and the Pliocene.

In the early Tertiary, the mammal life of North America and western Europe passed through similar phases. The first stage, according to Osborn, comprised the archaic phase of the Palæocene; the second, a long phase, in which the archaic and modern mammals of the Lower Eocene intermingled; the third, a very prolonged period from the Lower to the Upper Eocene, in which Europe and North America were widely separated and each of the ancestral types of mammals underwent an independent evolution. This was followed in Oligocene time by a phase in which the animal life of western Europe and North America was reunited.[1]

Again, in Miocene time a further wave of European mammalian life swept over North America, including the advance wave of the great order Proboscidea, embracing both mastodons and elephants, which appear to have originated in Africa or in southern Asia. During the entire Miocene and Pliocene epochs there is more or less unity of evolution between North America, Europe, and Asia, but it is a very striking fact that in mid-Pliocene time, when a wave of South American life entered North America, certain very highly characteristic forms of North American mammals (camels, etc.) entered Europe. In late Pliocene and early Pleistocene time, the grandest epoch of mammalian life was reached; certain great orders like the proboscidians and the horses, with very high powers of adaptation, as well as of migration, spread over every continent except Australia.[2]

The modernized mammals include the following groups besides the insectivores, which are considered by some as survivors of the archaic types.

1. Carnivora — or true flesh-eaters.
2. Rodentia — or gnawing animals.
3. Perissodactyla — or odd-toed ungulates.
4. Artiodactyla — or even-toed ungulates.
5. Proboscidea — elephants and mastodons.
6. Cetacea and Sirenia — whales and sea-cows.
7. Primates — lemurs, monkeys, apes, and man.

[1] *Origin and Evolution of Life*, H. F. Osborn, p. 261. [2] Osborn, *loc. cit.*, p. 262.

Carnivores

These include the dog, cat, bear, civet, raccoon, and seal tribes, both living and extinct representatives. The dogs (including wolves and foxes) appeared simultaneously in Europe and North America in the late Eocene, but in each continent they were represented by different genera. These may have been developed from a common ancestor in the northern home and, migrating in opposite directions, may each have undergone a different development. Modern domestic dogs and wolves seem to have been developed from the American stock, which then migrated to Asia by the Behring Strait land-bridge. There it flourished, while the American forms died out. When the true dog genus (*Canis*) had arisen, it spread to Europe in the late Pliocene, then to Africa, and finally back to America, reaching the home of its extinct ancestors in Pleistocene time.

Meanwhile in Europe there developed dogs with many bear-like characters, and these became the dominant carnivores of the Old World in Miocene time before the true dogs or wolves (*Canis*) and the true cats (*Felis*) had reached Europe, though saber-tooths (*Machærodus*) were already existing there. These giant bear-like dogs died out in Europe when the true wolves appeared.

Cats are known first from Asia, whence they spread over the entire world with the exception of Madagascar and Australia. The race falls naturally into two great divisions, the biting cats (lions, tigers, pumas, etc., and domestic cats) and the saber-tooths. The latter developed, in the upper jaw, enormous stabbing canine teeth, which could pierce the toughest hides of the contemporaneous herbivores (Figs. 1946, 1947, p. 893).

Both groups of cats appeared simultaneously in western Europe and North America in Oligocene time and continued to develop along parallel lines in both continents. Both saber-tooths and the great cats (lions, tigers, leopards) became extinct in North America in comparatively recent times (Pleistocene), though small cats (jaguars, pumas, lynxes) continue to exist to the present. In the Old World, too, the saber-tooths became extinct after the appearance of man, but the great cats continued to live in Asia, whence they migrated to Africa.

The bears were probably descended from early dog-like ancestors, but their full history is still unknown. The oldest bears are found in the Miocene rocks of the Old World, but these creatures apparently did not reach North America until Pliocene time. They are now chiefly confined to the northern hemisphere.

The seals, sea-lions, and walruses represent a remarkable adaptation of the carnivores to an aquatic life, in which the arms and legs are modified into fins. In company with the bears they lack the characteristic flesh-cutting cheek, or carnassial, teeth which distinguish the jaws of typical carnivores. The seals and their relatives probably arose from land carnivores in the later part of the early Tertiary.

The Hoofed Mammals or Ungulates

Two distinct groups of hoofed animals are recognized: those in which the toes on each foot are even numbered, either 4 or 2 as in the pigs, hippopotamuses, camels, giraffes, deer, antelopes, sheep, goats, oxen, etc., and those in which they are of an odd number (5, 3, or 1) as in tapirs, rhinoceroses, and horses. The former are called *Artiodactyla* and the latter *Perissodactyla*. The even-toed type is often, though not always, characterized by paired horns, which are typically wanting in the odd-toed types, though a single one, or two unpaired horns, may exist, as in the rhinoceros.

Both of these groups are derived from ancestors with five toes on each foot, and the reduction of the number of toes can be correlated with a change in the mode of progression from ***plantigrade*** (flat-footed) or *digitigrade*, walking upon the toes, to an ***unguligrade*** mode of progression, where the animal has raised itself upon the tips of the toes in order to attain greater swiftness in running. Because of this, the shorter toes were seldom in contact with the ground, and so became aborted. This in one group began with the first and fifth, then followed the second and fourth, until only the middle or third one remains, as in the modern horse. In the other group the first toe or finger (thumb) was lost, then the second and fifth became reduced, until finally only the third and fourth remained, as in modern cattle. Corresponding changes took place in the bones of the fore and hind feet, this being in the odd-toed forms primarily a reduction until only vestiges remained (splint bones of the horse), while in the even-toed types there was further the union of the two middle bones of the foot into a solid " cannon-bone."

Artiodactyla or Even-Toed Ungulates

This order includes the following existing types:

1. Pigs, peccaries, and hippopotamuses.
2. Camels, llamas, and chevrotains.
3. Giraffes, deer, and prong-horn antelopes.
4. True antelopes, sheep, goats, musk-oxen and cattle.

We shall briefly note the characters and geological history of some of these.

Pigs, Peccaries, Hippopotamuses, etc. — The least specialized of the even-toed ungulates are the pigs, which arose in Europe, and the peccaries, which are of American origin. The foot of the pig is short when compared with that of the other members of the group, while only the first digit is lost, though the second and fifth have been reduced until they serve only the purposes of supplementary toes, the main weight of the animal resting upon the third and fourth digits, which are correspondingly enlarged (Fig. 1899).

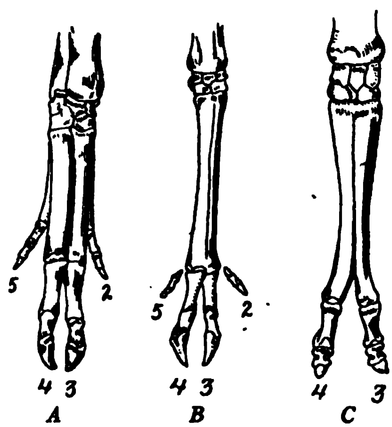

FIG. 1899. — Fore-feet of artiodactyls. *A*, pig, *Sus scrofa*; *B*, red deer, *Cervus elaphus*; *C*, camel, *Camelus bactrianus*. These show the progressive reduction in the number of lateral digits. The first is lost in all; digits 2 and 5 are small in the deer, forming the dew-claws; in the camel they have disappeared entirely, only digits 3 and 4 remaining. (After Flower.)

The home of pigs and peccaries was probably in Asia in Eocene time, one group migrating to Europe, the other to North America by way of the Behring Strait land-bridge. Many branches of pigs developed in Europe during Tertiary time, but all except a few became extinct, one of the surviving lines terminating in the wild pig and boar and the domestic pig of to-day. The wild pig first appeared in the Upper Miocene deposits of the Old World, migrating to the East Indies and to North and East Africa in Pliocene time. "Domestication by primitive man probably occurred in Asia, and as man spread over the world he carried with him this very important member of his primitive household. Eventually the pig was brought to America by the Europeans, and from these introduced domestic types our own wild or feral pigs were derived." The peccaries, the early American members of the pig tribe, arrived here from Asia probably in Oligocene time, and now range from Texas to Patagonia. America had, however, its peculiar pig-like animals in Tertiary time, which, like true pigs and peccaries, prob-

FIG. 1900. — Restoration of giant pigs, *Elotherium* (Entelodonts), which were common in the Middle Oligocene of Europe and America. They had stilted legs and elongated skulls and the entire body was of larger proportions than in the pigs of to-day. (Courtesy of Amerīean Museum of Natural History.)

ably originated in Asia, but had their chief development in this country. These were the giant *elotheres* and the cud-chewing swine or *oreodonts*. The elotheres or *entelodonts* blossomed out into a number of evolutional lines, all of which, however, became extinct in Miocene time. With many characters of the wild boar, they joined the long head and stilted legs, suggestive of the horse, and the thick neck of the rhinoceros (Fig. 1900). The oreodonts had a more slender neck, and the head was held more erect, while the feet were primitive, retaining four functional toes with a vestige of a fifth (the first, as usually counted) in the fore-foot or hand. Their teeth were a combination of the conical cusps of the pig and the crescent-shaped ridges of the typical and chewing ungulates. In size they were seldom larger than a sheep. They first appeared in the American Eocene, and did not become extinct until Lower Pliocene time. The final members of the group had developed a flexible upper lip and in some cases a short proboscis, like that of the elephant. These later forms probably led a semi-aquatic life, though most of the oreodonts were animals of the plains.

Most grotesque of all modern mammals is undoubtedly the hippopotamus, or "horse of the rivers." This is a derivative of the European swine, and though confined to Africa to-day, it ranged over Europe and Asia in Pliocene time.

Camels. — To-day camels are confined to the Old World, where they are represented by the one-humped Arabian camel or dromedary, and the two-humped Bactrian camel of Central Asia. There is, however, a South American humpless camel, the llama, with two wild and two domesticated species (llama and alpaca), but the race is to-day unknown in North America except by introduction. This country was, however, the cradle of camel life in the Tertiary, and from here they spread to Asia and other parts of the world.

The remains of the oldest known camel (*Protylopus*) were obtained from the Upper Eocene rocks of North America. It was of the size of a jack-rabbit and had 44 teeth, whereas the modern camel has only 34, 16 in the upper and 18 in the lower jaw. The fore-legs of the oldest camel were much shorter than the hinder ones, and the bones of the lower fore-leg were distinct and complete, unlike their condition in modern camels. The fore-feet had four digits, the two outer ones shorter but still functional, while in the hind-foot the two outer toes, though present, were useless. The bones of the fore-foot, too, were still separated. The progress of foot development of the camel consisted in the further reduction and final loss of the lateral digits and in the elongation of the two median bones of the fore-foot and their union into a "cannon-bone." The animals also progressively increased in size.

In the Oligocene, camels of the size of a modern sheep were abundant in Nebraska, Colorado, South Dakota, and elsewhere west of Oregon. Their lateral toes were by that time reduced to mere nodules and wholly useless; the bones of the lower fore-leg had united and the smaller bone of the hind-leg (fibula) had nearly disappeared, these changes making for greater rigidity of limb structure. The camels now divided into three branches, two of which became extinct after a while. The third again divided in the Pleistocene, one branch migrating into South America, where it gave rise to the llamas (*Auchenia*), the other entering Asia, where the two modern species survive, while all the North American species had become extinct, partly perhaps because of the cold of the glacial period, which did not affect Asia or South America.

Ruminants. — These animals chew the cud, an operation familiar to all who are acquainted with the habits of domestic cattle. The group includes the solid-horned or antlered deer and the giraffe, on the one hand, and the hollow-horned ruminants (antelopes, sheep, goats, and bovines), on the other. The antlers are formed as a modification of true bone, and are shed annually, being renewed in a few months. The true horns are permanent, consisting of a hollow horn, a modification of the skin, inclosing a bony core. In all of these animals the fused bones of the feet (3d and 4th metapodials) form a very long cannon-bone, ending in two digits, while in the deer two supplementary digits (2d and 4th) are represented by the "dew-claws" used in some species (reindeer and caribou) in walking on soft, mossy ground. In other words, the modern deer has not progressed so far in the development of the foot-structure as has the camel or the bovines (ox, cow, buffalo), being in this respect even less advanced than the ancestral camel of the Eocene (*Protylopus*). Because of the long cannon-bones, the wrist and ankle of the ruminants, as in the case of the camel and the horse, are found near the middle of the visible part of the fore and hind-legs, the elbow and knee being close to the body.

FIG. 1901.—Antlers of: *a*, *Cervus* (*Palæomeryx*) *elegans*, Miocene, Sansan; *b*, *C.* (*Pal.*) *anocerus*, Upper Pliocene, Eppelsheim; *c*, *C. matheroni*, Upper Pliocene, Mt. Luberon; *d*, *C. martialis*, Pliocene, St. Martial. (All about $\frac{1}{10}$ natural size.)

The antlers of the male deer or stag (in the reindeer and caribou they are also developed in the female), increase in complexity from year to year by the addition of new prongs. In the first year only frontal protuberances (fossets) are developed. In the second year the antlers are simple spikes, and in the third a prong appears, after which a second and third prong appear in the fourth and fifth years, respectively, the number continuing to increase yearly. This complexity parallels that developed during the history of the deer tribe as a whole (Figs. 1901, 1902). Thus the adult deer of the Middle Miocene had only two prongs to its antlers, that of the Upper Miocene three, of the Lower Pliocene four, while still more recent forms had five prongs. These successive ancestral antler characters are therefore repeated in the individual development of the modern deer.

FIG. 1902. — Antlers of *Cervus sedgwicki* (× about $\frac{1}{80}$), Upper Pliocene, Valley of the Arno.

Perissodactyla or Odd-toed Ungulates

This division includes the following families: 1, Palæotheres; 2, Horses; 3, Titanotheres; 4, Tapirs; 5, Lophiodonts; 6, Hyracodonts; 7, Rhinoceroses; and 8, the peculiar aberrant Chàlicotheres. A few of these may be noted more fully.

Palæotheres. — Among the bones found in the gypsum quarries of Paris and vicinity were those of a peculiar animal which possessed characters of the modern horse and the tapir. These animals, to which the name *Palæotherium* has been applied, lived only during the older Tertiary, dying out in Oligocene time and apparently leaving no descendants. The Palæotheres were browsing animals, and they had a short proboscis, or upper lip, modified into a grasping organ, as in modern tapirs. The teeth were like those of the extinct forest-horse of America and, as in that animal, both fore and hind limbs were furnished with three toes.

Horses. — Present indications point to America as the ancestral home of the horse, though horses were not living in America when fore-leg had united and the smaller bone of the hind-leg (fibula) had nearly disappeared, these changes making for greater rigidity of limb structure. The camels now divided into three branches, two of which became extinct after a while. The third again divided in the Pleistocene, one branch migrating into South America, where it gave rise to the llamas (*Auchenia*), the other entering Asia, where the two modern species survive, while all the North American species had become extinct, partly perhaps because of the cold of the glacial period, which did not affect Asia or South America.

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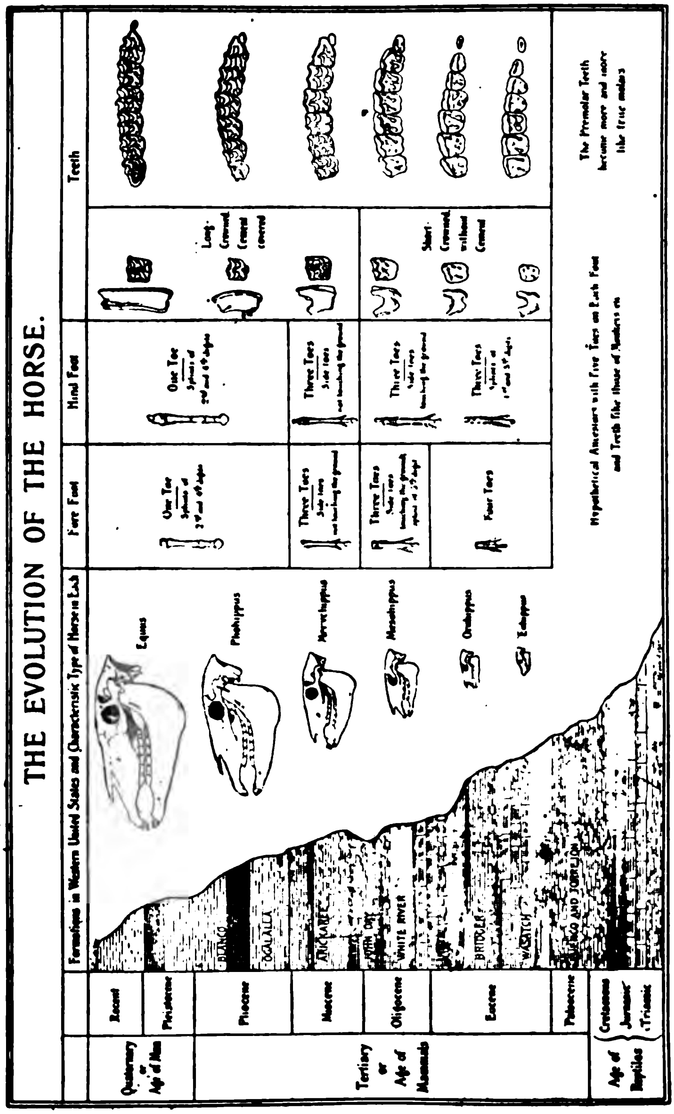

FIG. 1904.—Diagram illustrating the evolution of the horse. After Osborn. (Courtesy of American Museum of Natural History.) (*Note:* The correlation used in this book places the dividing line between Palæocene and Eocene in the lower Bridges.)

The two bones of the fore-arm (*radius* and *ulna*) and of the shin (*tibia* and *fibula*) are still distinct in *Eohippus*, but in succeeding forms one of each (ulna of the arm, fibula of the leg) becomes reduced and finally disappears. As a result, the rotary power of arm and leg is lost, but greater rigidity, necessary for fleetness, is gained. *Eohippus* gave rise to the Eocene *Orohippus* (Fig. 1907), in which the structure of the foot, though still four-toed, has advanced by loss of the splint which represents the fifth digit of the hind-foot, and the decrease in size of the fifth digit of the fore-foot. The teeth, also, are more specialized. *Epihippus* is

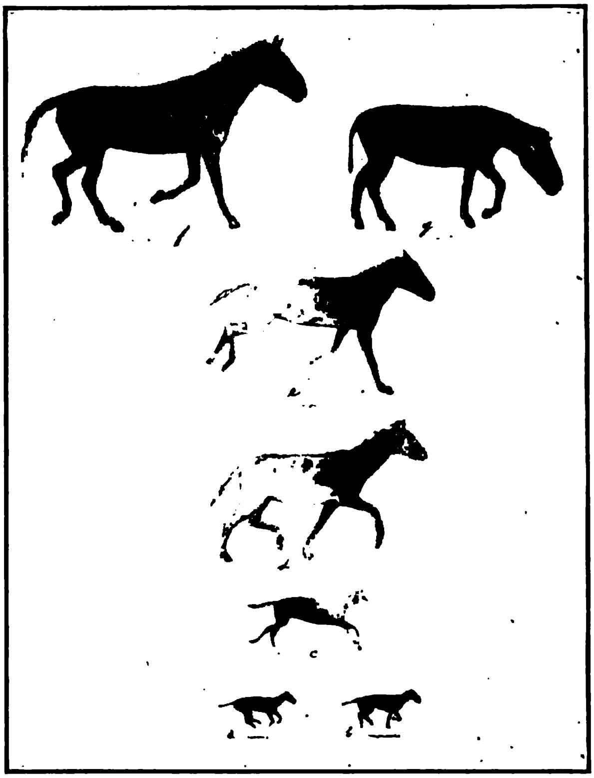

FIG. 1905. — A series of restorations of the horses from the Palæocene to the Quaternary, showing form and relative size. At the bottom are (*a*) *Eohippus* (on the left) and (*b*) *Protorohippus* (on right) (Palæocene); next above these (*c*) is *Mesohippus*; then (*d*) *Hypohippus* and (*e*) *Neohippus*. At the top are (*f*) *Hippidium* (on right) and (*g*) *Equus scotti* (on left).

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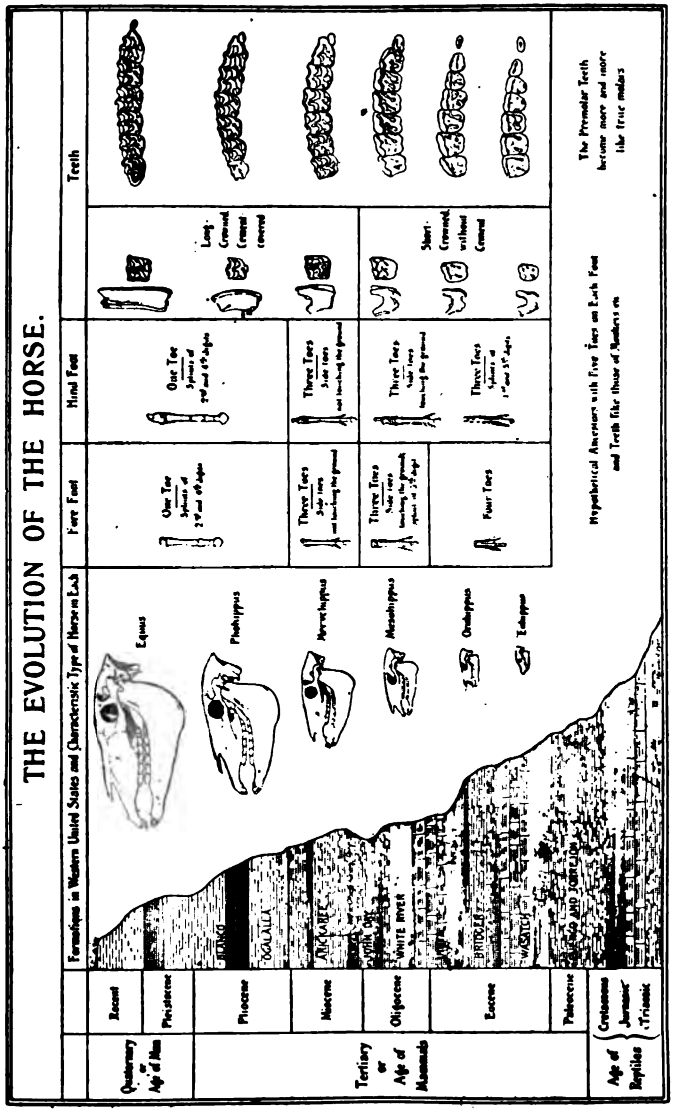

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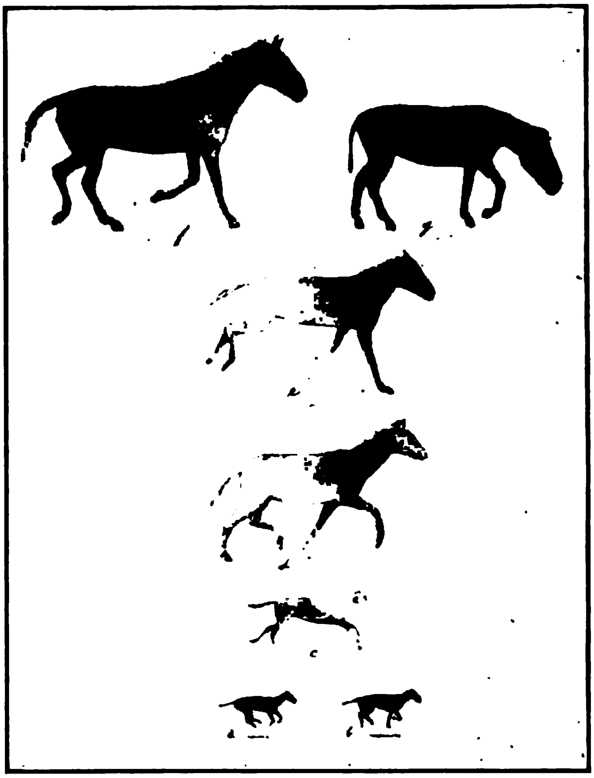

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1904) and *Protohippus*, together with several lateral branches which became extinct, one of them having reached Europe. The chief modification of the foot of these three-toed horses of the Oligocene and Miocene was in the increase in size of the middle and the decrease of the lateral toes. The tooth structure also steadily advanced in complexity and the animal continued to increase in size.

Protohippus gave rise to the Pliocene *Pliohippus* (Fig. 1904), the direct ancestor of *Equus*, and also to two other forms, one of which, *Hyparion*, migrated to Europe, where it became extinct,

FIG. 1910. — Restorations of Eocene titanotheres. (After Osborn.) (Courtesy of American Museum of Natural History.)

while another (*Hippidium*, Fig. 1905), migrating to South America, left descendants which continued into the Pleistocene and then died out. These Pliocene horses had become one-toed, but not to the extent seen in the modern horse. The lateral toes still remained as functionless " dew-claws."

Equus, the true horse, with the lateral toes represented only by splints and with highly complicated teeth, arose in the late Pliocene and migrated both to South America and to Eurasia. It lived until the Pleistocene, when it became extinct in both North and South America, but continued in Eurasia. From the survivors of these, the modern horses have been derived and have been introduced by man all over the world. They have, in some cases, again become wild or *feral*, as in western North America and in South America, where horses were introduced, in Buenos Ayres in 1537, and rapidly spread, so that in forty years they had extended their range to the Straits of Magellan.

In its Asiatic asylum, and in North Africa, the horse gave rise to several special groups, such as the ass, the zebra, and others, some of which have again been widely distributed by man.

Titanotheres. — These animals, too, represented a distinctively American type of odd-toed ungulates, confined to the early Tertiary. They belong to one of many groups of mammals which rapidly rose to high specialization and dominance and as rapidly suffered decline and total extinction. .These animals (Figs. 1910,

FIG. 1911. — Restorations of Oligocene titanotheres. (After Osborn.) (Courtesy of American Museum of Natural History.)

1911) were clumsy-bodied, with short, stout legs, a flattened head generally bearing horns, and with a superficial resemblance to the modern rhinoceros, to which, however, they were only distantly related. Their leg and foot structure remained primitive, the two bones of the forearm and lower leg continuing distinct, while the toes were all functional. The head was perhaps the most peculiar part of the animal, the roof of the skull being flattened and, in a highly specialized member, the *Brontotherium* (Fig. 1912), bearing a large bifurcating and flattened horn on the top of the nose. The earlier members of the group were small animals without horns, the latter appearing first as low knobs in their successors

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FIG. 1914. — Restoration of *Teleoceras*, a short-limbed rhinoceros which inhabited Europe and North America during the Upper Miocene or Lower Pliocene. (Courtesy of American Museum of Natural History.)

exceeded in bulk the largest living rhinoceros. Such progressive increase in size, followed by extinction, is very general among mammals as among other animals.

Hyracodonts. — The ancestors of the rhinoceros were horse-like,

FIG. 1915. — *Moropus*, the remarkable ungulate Chalicothere with claws instead of hoofs. (Upper Oligocene to Upper Miocene of North America.)

swift-running, hornless animals (*hyracodonts*) which lived in North America in Eocene time (Fig. 1913). An aquatic group of rhinoceros (*amynodonts*) also appeared at this time. They were adapted to river life, were without horns, but had canine teeth or tusks like those of the wild boar. This group was short-lived, becoming extinct in Oligocene time.

Rhinoceroses. — These animals lived in America and in Europe in Oligocene time and continued into the later Tertiary and Quaternary, finally becoming extinct except in Asia and Africa. No less than seven distinct evolutional lines of rhinoceroses arose, developing along parallel but independent lines. Four of these became extinct (*Teleoceras*, Fig. 1914, etc.), but the other three have each a surviving member, *i.e.*, the Sumatran two-horned rhinoceros, with large cutting-teeth, the African two-horned rhinoceros without cutting-teeth, and the Indian and Javan one-horned rhinoceros. The rhinoceros has not developed beyond the three-toed stage, though the middle toe is generally the largest and longest.

Chalicotheres. — These comprised a peculiar group of ungulates with a composite structure, and they were wholly confined to the Tertiary. Their teeth were those of typical ungulates or hoofed animals, but their feet ended in claws instead of hoofs. These claws are a secondary reversion to an older type of foot structure adapted for digging purposes. A typical American representative was *Moropus* (Fig. 1915).

In addition to these ungulates, there was a peculiar group, the *Notoungulata*, which arose in early Tertiary time and became extinct in the Pleistocene, but which, throughout its history, was confined to South America. Of its 27 genera some had grinding teeth like the rhinoceros, others had the grinding teeth of horses, and still others were mastodon-like in character.

The Proboscidea

The great group of Proboscidea, or elephants and their kin, has only two survivors, the Asiatic elephant (*Elephas*) and the African elephant (*Loxodonta*), but in times not so far remote, mastodons and mammoths lived in the forests and jungles of Europe and America, the contemporaries of primitive man. Elephants differ from other ungulates or hoofed animals in many characters, some of which are primitive, others specialized. Among the first is the retention of five toes in the fore and hind feet, and the distinctness of the bones of the shin and fore-arm, in which, moreover, the bone which is usually the smaller in the arm (ulna) has become the larger of the two. Specialization is seen in the trunk, the shortening of the neck, the remarkably developed, though in some respects still very primitive, brain, the tusks, which are the greatly elongated second upper incisor teeth, and the complex character of the molars or grinding teeth, and the fact that there are at one time never more than one complete or two partial grinders in each half of the jaw. "The first molar appears during the second week

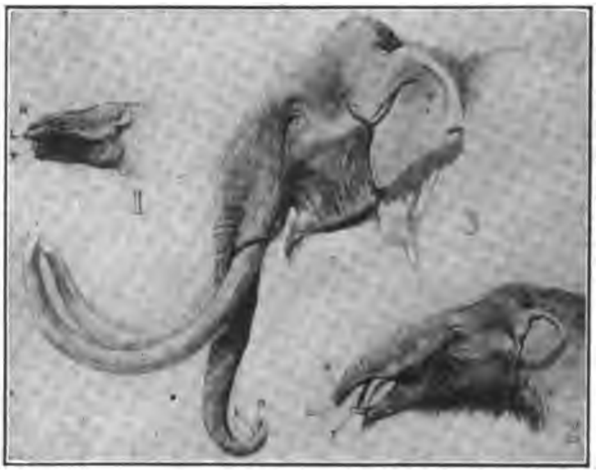


FIG. 1916. — Three stages in the evolution of the elephants. 1, *Mœritherium*, Eocene; 2, *Palæomastodon*, Oligocene; 3, Elephant, Recent. (After Osborn. By courtesy of the American Museum of Natural History.)

(after birth), is complete and in full use at three months, and is shed when the elephant is about two years old. The second molar has most of the plates in use at two years of age and is shed at six: the third appears at two, is at its maximum at five, and is shed at nine. These are looked upon as milk molars. The first true molar, which is the fourth grinder in succession, appears at the sixth year and is shed from twenty to twenty-five; the fifth shows its crown at twenty and is shed probably at sixty, and the last molar appears at from forty to fifty years and lasts out the century." (Lull, *Organic Evolution.*)

The ancestor of the elephant has been obtained from the lower Oligocene rocks of Lake Mœris in the Fayum district of the Libyan

Desert, some sixty miles southwest of Cairo. This "beast of Lake Mœris," or *Mœritherium* (Fig. 1916), as it has been called, stood only three and one-half feet high, while the great African elephant, Jumbo, stood eleven and the extinct mammoth fourteen feet in height. This ancestral form had neither trunk nor tusks, though the incisors are well developed, those of the upper jaw pointing downward and those of the lower forward. There are also indications in the structure of the skull that the trunk will develop in time by the elongation of the combined upper lip and nose.

FIG. 1917. — ***Dinotherium giganteum***, Upper Pliocene, Eppelsheim, skull $\frac{1}{25}$ natural size. (From Steinmann.)

Mœritherium gave rise to *Palæomastodon* (later Oligocene, Fig. 1916, 2), which had short, curved tusks in the upper, and forward-projecting incisors in the lower jaw, and a very short proboscis. It also gave rise to *Dinotherium* (Fig. 1917), a distinct branch which invaded Europe and Asia, and became extinct in Pliocene time, reaching truly elephantine size. Unlike the true elephants, its tusks were developed from the incisors of the lower jaw and hung downward from the chin-like hooks, and were over-arched by a short proboscis.

Trilophodon (Fig. 1918), the Miocene elephant, had comparatively long, gently curved tusks in the upper, and short forward-pointing ones at the end of the projecting lower jaw, while its trunk had become of considerable length. From this Miocene elephant arose the mastodons, *Stegodon*, and the true elephants, and the tetralophodonts and dibelodonts, in nearly all of which the lower jaw was shortened and the tusks of the upper jaw elongated. The grinders of the mastodons had few strong ridges, separated by deep valleys with little or no cement in them, while elephants (including mammoths) have many crested grinders with the valleys filled by cement (Fig. 1965, p. 904). Mastodons (Fig. 1961, 1962, p. 902) came to North America in Pleistocene time and then became extinct.

Tetralophodon came to North America in Miocene time, giving rise to *Dibelodon*, which migrated to South America and became extinct in Pleistocene time. The true elephants arose in Asia, migrated to North America in the Pliocene era, and became extinct here in the Pleistocene. They continued to live in Asia to the present time and also sent a branch to Africa, where it still exists. *Tetralophodon* had straight, forward-pointing tusks, a long upper and a short lower pair. *Dibelodon* had much longer, gently flexed upper tusks, but no lower ones. The mastodons, mammoths, and elephants had only long, more or less curved, upper tusks, but no lower ones.

The ancestral elephant (*Mœritherium*) was itself derived from a still unknown earlier type, from which also arose the aquatic

FIG. 1918. — Skull of primitive mastodon, *Trilophodon productus*, from the Miocene of Texas, $\frac{1}{18}$ natural size. (After Osborn; from Matthew.)

relatives of the elephant, the sirenians or sea-cows. These are to the ungulates what seals, sea-lions, and walruses are to the carnivores, namely, animals modified so that they can live in water. The elephants developed from the ancestral stock chiefly by modification of the head, while in the sirenian, the change is mainly in the legs and tail, to adapt them for swimming.

The Cetaceans

The whales, dolphins, and their kin are aquatic mammals of ancient lineage. Most of them live in the sea, where two groups are recognized, — the toothed whales, including dolphins, narwhals, and sperm-whales, and the baleen or whale-bone whales, in which great sheets of horny matter replace the teeth. A third group, the zeuglodonts, or archaic cetaceans, also lived in the sea, and are

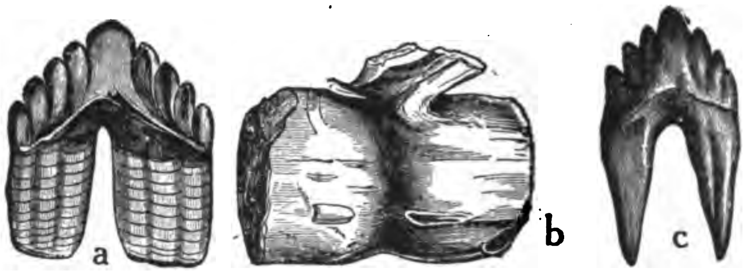


FIG. 1919. — *a, c*, the yoked tooth (two-rooted) and *b*, a vertebra of *Zeuglodon cetoides* (reduced).

known as far back as the Eocene of Africa and North America. These ancient whales were more like huge sea-serpents because of the greatly elongated vertebræ or bones of the spinal column

FIG. 1920. — One of the early marine mammals, the primitive whale (*Zeuglodon cetoides*) from the Eocene of Alabama. These whales reached a length of upward of seventy feet, but were thin and tapering, measuring only six or eight feet in greatest diameter. They had a pair of short fore paddles, but the hind limbs were vestigial, remaining beneath the skin in an undeveloped condition. *Zeuglodon* lived in the waters of the early Tertiary Gulf of Mexico and in the seas of southern Europe and northern Africa. (Courtesy of the American Museum of Natural History.)

(Figs. 1919, 1920), and they were widely distributed in the ancient seas before they became extinct. Cetaceans have lost their hinder legs, of which, however, vestiges remain buried in the flesh. The fore-limbs are modified into paddles, and the tail is a powerful organ of propulsion, ending in a double fin or "fluke." The hair, so characteristic of the other mammals, is entirely lost, and in its stead a layer of fat, the blubber, is developed beneath the skin, to keep the animal warm.

CHAPTER XLVII

THE PSYCHOZOIC OR QUATERNARY SYSTEMS

The Quaternary comprises the *Pleistocene* and the Recent or *Holocene* systems. The name Quaternary is sometimes restricted to the Pleistocene, and included with the Tertiary in the Cenozoic division, while the term Psychozoic is restricted to the post-Pleistocene or recent division of the earth's history. It is, however, a well established fact that man, the characteristic organism of Psychozoic time, was already well developed in later Pleistocene time, and that his origin fell early in that period. Therefore it is perfectly logical to unite the Pleistocene and the Recent into the Quaternary or Psychozoic era of the earth's history.

The Quaternary of America

Marine Quaternary deposits are, for the most part, scanty within the area of the present continents, though in some cases the margins of the continents were flooded and overspread by a layer of marine sediments. Most of the deposits formed in the sea of that time were within the region of the present oceans, and so are not open to investigation. Continental deposits, however, were abundant and of varying types, most prominent among them in North America and Europe being those of the great ice-sheets which overspread these continents.

The Ice Age in North America

That a large part of North America was covered by ice during the Pleistocene period is inferred from the fact that throughout Canada and the northeastern United States, the older rocks are covered by a deposit of boulder clay or till, generally an unstratified mixture of clay, rock-flour, pebbles, and boulders, some of the latter being of huge dimensions (Fig. 1923). The boulders and large pebbles commonly show polished and striated surfaces such as are known to be characteristic of glacially transported material (Fig. 360 *a*, p. 435, Pt. I; Fig. 419, p. 497, Pt. I). Moreover, the rock surface upon which this boulder clay rests is usually fresh and smooth (Fig. 26, p. 65, Pt. I) and frequently polished and marked by one or more series of parallel striations of the type made by modern glaciers upon the rocks over which they move (Fig. 359, p. 434, Pt. I). Occasionally the striations are supplemented by deep, parallel flutings or groovings, some of the most striking of which have been found upon the limestone surface of Kelly's Island in Lake Erie (Fig. 421, p. 499, Pt. I) though similar ones are found in widely separated districts of the country. These evidences of glacial erosion are supplemented in the low countries by extensive overdeepening of preëxisting (Tertiary) river valleys, the cutting off or truncating of the projecting rock spurs on the sides of these valleys, and the steepening of the marginal slopes. In this process the lateral valleys which entered the main stream at grade are now left as hanging valleys on the side of the overdeepened stream (p. 801, Pt. I). In the higher countries, evidence of glacial erosion is also marked. (See p. 800, Pt. I.)

The till is of the kind found to-day beneath large glacial sheets, and the rock masses which it contains have clearly been transported for some distance, occasionally for hundreds of miles. In some regions, notably Massachusetts, New York, and Wisconsin, the till locally thickens into rounded or elongated elevations, the *drumlins* which have already been described (Fig. 420, p. 498). Terminal moraines, similar in general character to those formed at the foot of modern glaciers, are found not only near the southern limit of the till-covered area, but also within that area, at a number of localities. Such terminal deposits within the till-covered area overlie that till, and mark a temporary resting stage of the ice during a period of its frontal melting, or after a period of readvance. Other marginal or submarginal deposits also abound, such as sand-plains or deltas built into temporary bodies of water, outwash or apron plains, kames, and eskers (pp. 502–507, Pt. I).

In many regions, more than one layer of till is found, while between the layers are deposits of various kinds (river-laid, lake, swamp, and wind-laid deposits, peat, etc.), many of which contain the remains of plants and of animals which belong to types at home in genial climates. Moreover, the older drift-sheets are commonly much more strongly weathered than the newer, the clays being more thoroughly oxidized, and the boulders frequently affected by disintegration. The materials of the several drift-sheets differ, because the source has generally been different for each ice lobe. Finally, older drift-sheets may have been more or less eroded before the peat and other deposits which separate them from the younger drift-sheets were formed. This leads to the inference that the glaciation of the country was not simple, but complex, the ice which was responsible for the till and the material of the frontal deposits disappearing after a time, to give way to a period of milder climate in which the plants and animals, previously driven south by the advancing ice-sheet, were able to return and to reoccupy the territory from which they had been excluded. Such interglacial periods of warmer climate were brought to a close again by the readvance of the ice which covered these deposits with a second layer of till or other glacial material.

In North America five periods of ice advance are indicated by the glacial deposits, and at least four intervening periods of milder climate by the interglacial deposits. The Holocene or present period of restricted glaciation is sometimes considered as representing the fifth interglacial period. The succession of glacial and interglacial periods and their deposits in North America is as follows:

5. POST GLACIAL OR RECENT (HOLOCENE) TIME. — Dwindling away of the ice-sheets; partial marine submergence of St. Lawrence and of Lake Champlain region; development of Great Lakes; extinction of giant mammals (elephants, mastodons, *Megalonyx*, etc.).

V. FIFTH OR WISCONSIN GLACIAL STAGE.

4. FOURTH OR PEORIAN INTERGLACIAL STAGE. — Peat and soil formation, extensive distribution of loess.

IV. FOURTH OR IOWAN GLACIAL STAGE.

3. THIRD OR SANGAMON INTERGLACIAL STAGE. — Peat, soil and loess accumulation. Fauna includes horses, elephants, mastodons, bison, peccaries, tapirs, etc.

III. THIRD OR ILLINOIAN GLACIAL STAGE. — Fauna of preceding interglacial stage continues to exist. Perhaps 60% of present land fauna then living.

2. SECOND OR YARMOUTH INTERGLACIAL STAGE. — Peat, soil and loess (bluish) formation. Fauna includes mastodons, mammoths, horses, tapirs, bisons, deer, saber-tooth tigers, etc.

II. SECOND OR KANSAN GLACIAL STAGE. — Extinction of some of the camels and horses.

1. FIRST OR AFTONIAN INTERGLACIAL STAGE. — Fauna abounds in mylodons, megatheriums, *Megalonyx*, mastodons, elephants (3 species), horses (6 species), camels (4 species), saber-tooth tigers, bears, etc.

I. FIRST OR SUB-AFTONIAN OR JERSEYAN GLACIAL STAGE. — Includes all the older tills, such as the Pre-Kansan, Nebraskan, Albertan, etc.

The complete series of stages is not found in any one place, for in a given region seldom more than two (or three) glacial tills with their interglacial deposits are seen. But by comparing the character of the deposits, and especially the faunas of the interglacial beds in different localities, the complete order of succession may be ascertained. It must be emphasized that the actual succession and the number of glacial and interglacial stages is not as yet fully determined, there being for example some doubt as to the Iowan glacial and the Peorian interglacial stages. Some geologists, indeed, recognize only three glacial stages. Others hold that there are six, the Wisconsin being regarded as a double stage.

Extent of Glaciation

Three large and several smaller ice masses or continental glaciers have been recognized as formerly existing in North America. Over the northeastern countries, east of Hudson Bay, lay the Labrador ice-sheet, which sent its lobes southward to Long Island on the east, and nearly to Cincinnati on the west. The "backbone" of

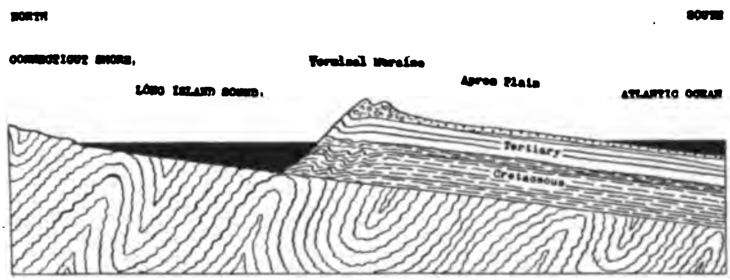
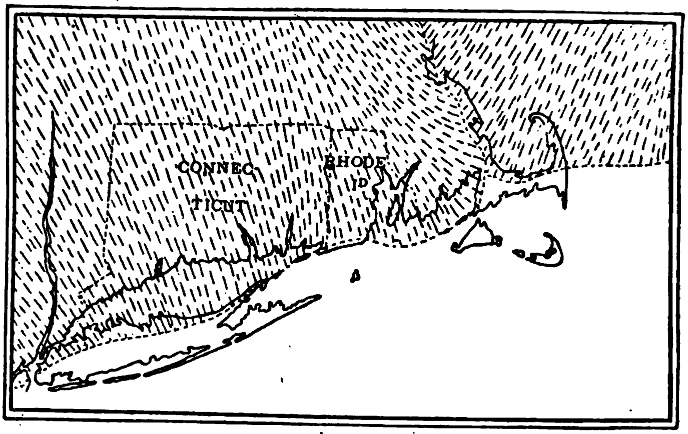
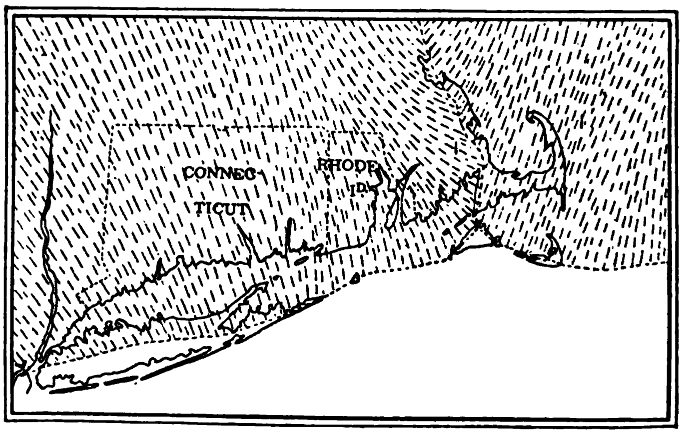


Fig. 1921. — Section across Long Island, N. Y., showing the cuesta-topography cut from the coastal plain strata; capped by the terminal moraine. The remnant of the coastal plain strata is veneered over by the outwash material of the apron-plain. (Original.)

Long Island is the terminal moraine of this lobe. It was piled on top of the cuesta cut from the Tertiary and Cretaceous coastal plain strata, which the ice deformed to some extent by the pressure against them during its advance (Fig. 1921). In front of the moraine, and covering the coastal plain strata, are the sands of the apron-plain, formed by overwash from the melting ice. On Long Island the moraine is really double, though the two parts are united on the western end, and thence continue westward to



b.



a.

FIG. 1922 *a, b.* — Maps showing the position of the ice-front and the formation of the terminal moraines: *a,* the first stage; *b,* the second stage after a partial retreat of the ice-front. (After J. Howard Wilson, ***The Glacial History of Nantucket and Cape Cod;*** Columbia University Press.)

Staten Island and New Jersey, being cut by the "Narrows" of New York harbor. Eastward on Long Island the two moraines become distinct, one forming Orient Point and Plum Island, and the other Montauk Point. The southern moraine is continued eastward, through Block Island to the western border of Martha's Vineyard, this island being composed of two moraines diverging from its northern apex with an apron-plain between (Figs. 1922 *a, b*).

The northern moraine is continued in the Elizabeth Islands of southern Massachusetts (Fig. 1922 *b*). From their eastern end a north-south moraine is traceable from Woods Hole to Plymouth

FIG. 1923. — Section of frontal moraine on the side of Warner Street, Gloucester, Mass. This is one of the many frontal moraines marking the steps in the retreat of the Pleistocene ice-front. (After Shaler, U. S. G. S.)

and at intervals to Cape Ann in Massachusetts (Figs. 1923, 1924). This north-south moraine was of the "interlobate" type, that is, it lay between two ice-lobes or two ice-sheets, the Labradoran on the

FIG. 1924. — Crest of the northern frontal moraine on Dogtown Common, Cape Ann, Mass., showing its bouldery character. (After Shaler, U. S. G. S.)

west and another on the east, regarded by some as a lobe of the Labrador sheet, by others as independent and centering in Newfoundland and Nova Scotia (IV in Fig. 1927). This eastern lobe or

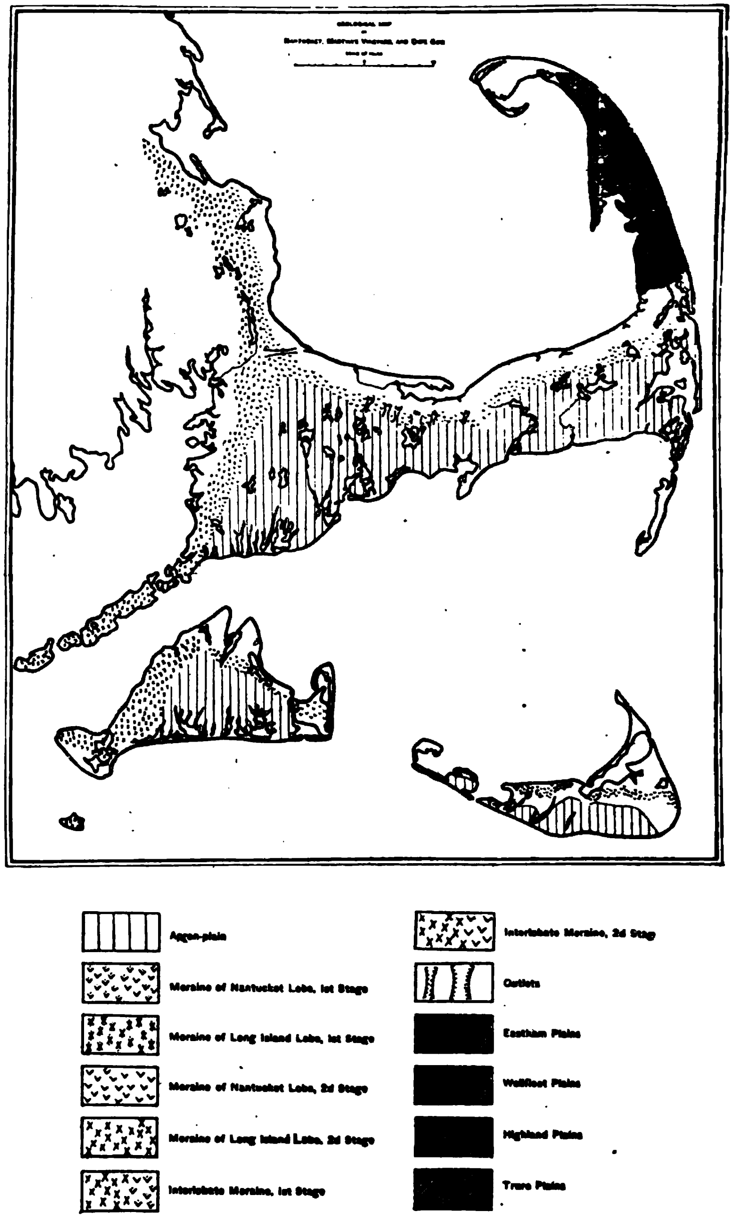


FIG. 1925.—Map of Cape Cod and the islands south of it, showing the location of the terminal moraines. (After J. H. Wilson.)

sheet built its terminal moraine along the eastern side of Martha's Vineyard and the northern border of Nantucket, the remainder of these islands being formed by the apron-plain. It has long been known that this moraine contains rocks of different type from those found on the western side of Martha's Vineyard and the Elizabeth Islands, and this is explained by the fact that these moraines were built by different lobes, or different ice-sheets, bringing débris from different sources. The eastern lobe after a while melted back for some miles and then built a new east-west moraine, which forms the backbone of Cape Cod, the

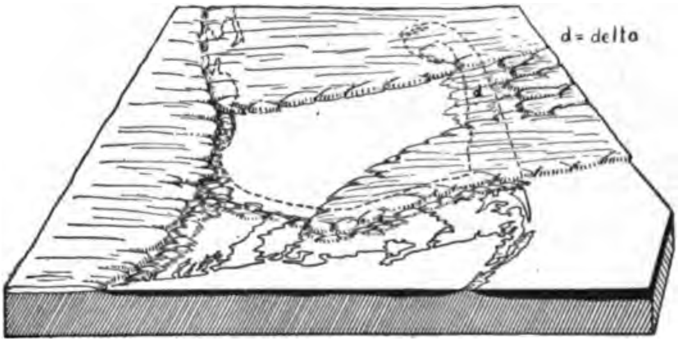


FIG. 1926. — Block diagram, showing the glacial Lake Shaler (Wellfleet stage) in the Cape Cod region. This lake was held in an embayment in the eastern ice lobe, and dammed by the front of the western ice lobe on the west, and the terminal moraine on the south. (Drawn by Mary Welleck.)

southern part of which is formed by the apron-plain (see map, Fig. 1925). The fore-arm of Cape Cod, which extends northward to Provincetown, with the exception of this last-named district, consists of a series of sand-plains or deltas which were built into standing water held in an embayment against the moraine as the ice-fronts continued to melt back (Fig. 1926). The levels of the various stages of this glacial Lake Shaler, as it has been called, are shown by the heights of the several sand deltas and were determined by the low points in the moraine, over which the water drained, as these points were progressively uncovered.

On the west, the Labradoran sheet came in contact with the largest of the ice-sheets, the Keewatin, which centered in the plains west of Hudson Bay and thence spread radially in all directions. Along the line of contact of these two sheets, in central Wisconsin, is an area free from drift. This " driftless area " either was never covered by the ice, or was buried beneath a mass of stagnant ice forming the center of a quiet area around which the ice currents flowed (Fig. 1927).

The third of the three larger ice-sheets centered in the Cordilleran Mountains of Canada and flowed both westward to the

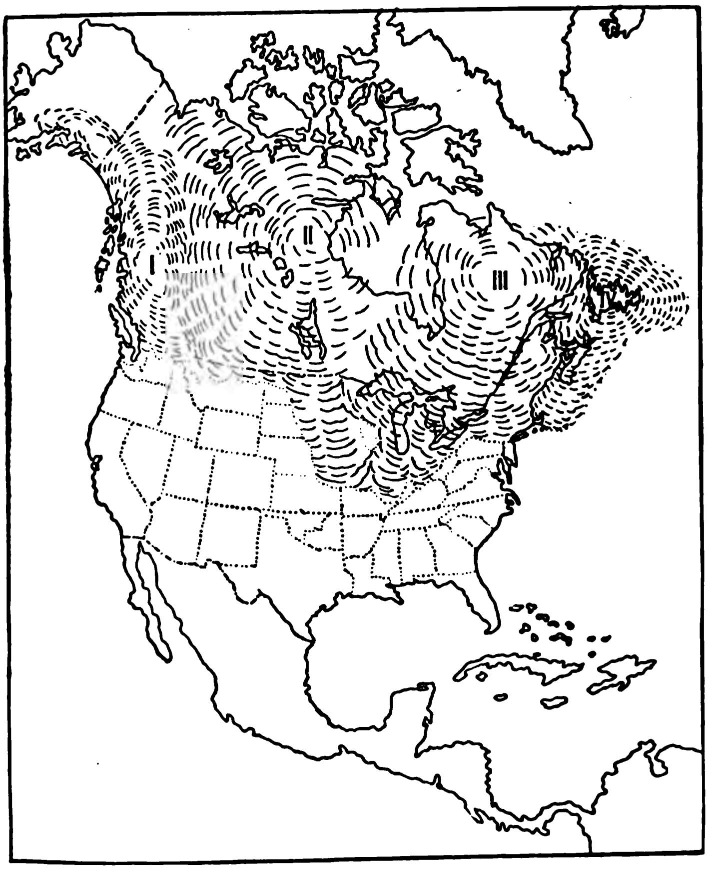


Fig. 1927.—Map of the Pleistocene ice-sheets of North America. I, Cordilleran; II, Keewatin; III, Labradoran; IV, Newfoundland. (After J. H. Wilson, *The Glacial History of Nantucket and Cape Cod;* by permission of Columbia University Press.)

Pacific and eastward, where it abutted against the western border of the Keewatin sheet (see Fig. 1927). Local alpine glaciers also existed in the Rocky Mountains, the Coast Range, and the Sierra

Nevada of California, while the ice-cap of Greenland was more extensive then than now. Alaska, however, seems to have been largely free from ice. The thickness of the ice in the central parts of the larger sheets was probably not less than 4000 feet and most likely much more. By some, a thickness of 10,000 feet has been assigned to the central Canadian ice masses (Le Conte).

Waning Stages of the Ice-Sheets

As the front of the ice-sheets melted during the warmer stages between advances, many local lakes, held up by ice-dams, were formed, and in these deposits of various kinds were laid down.

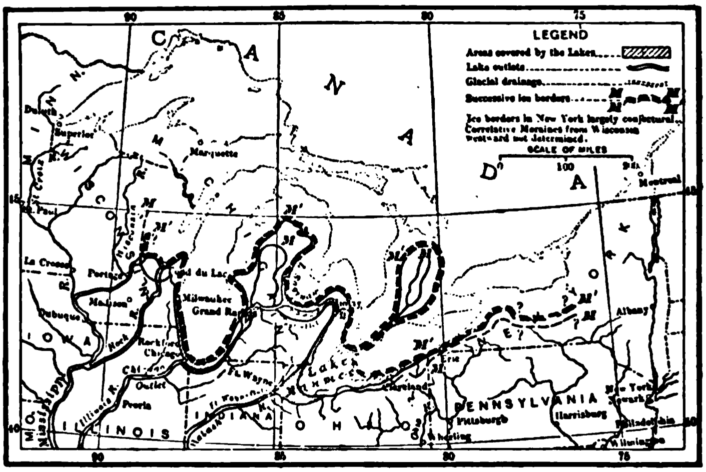


FIG. 1928. — An early (first) stage in the history of the Great Lakes. (After Taylor and Leverett.)

In general only those formed by the last melting period are preserved, and some of these have been worked out in detail, but many others still remain to be investigated.

The Great Lakes. — We have seen (p. 725, Part I) that the valleys of the Great Lakes, as well as the Finger Lake Valleys of New York, were originally formed by normal river erosion during Tertiary time. Many more or less radial consequent streams had appeared upon the gently domed surface of the old Cretaceous peneplane, while along the outcrop of the softer beds, the subsequent streams cut longitudinal valleys. One of these was the valley of Lake Ontario, another that of Georgian Bay, a third the main valley of Lake Huron, while lakes Erie and Michigan were compound valleys of this type. Lake Superior, on the other hand, had a more complex origin. During the glacial occupancy of this region, the former outlets of these valleys, the consequent streams which carried the drainage to the Mississippi, were largely choked by drift, while the subsequent valleys were themselves modified by it. Moreover, the entire region was depressed, partly, no doubt, because of the weight of the ice-sheet. As a result, when the ice melted from this region, the valleys had become closed and tilted basins, and they were quickly filled with water from the melting ice. At first a number of separate lakelets came into

FIG. 1929. — A (third) stage, in which three Great Lakes, with separate outlets, were formed by the further retreat of the ice-front. (After Taylor and Leverett.)

existence as the ends of the basins were uncovered. The first was in the western end of Lake Erie and the adjacent lowlands (Lake Maumee, Fig. 1928). Later the western end of the Superior basin was occupied by Duluth Lake, the greater part of the Michigan basin by Lake Chicago, and the Erie basin by Elkton Lake. These drained toward the Mississippi, and their outlines are traceable by the old beaches around their margins (Fig. 1929). Still later the upper three basins (Superior, Huron, and Michigan) united into the expanded Lake Algonquin, which drained by the Illinois River to the Mississippi and across Canada by the Trent River to the Ontario basin, which was then expanded into Lake

Iroquois (Fig. 1930). This lake is outlined by the now abandoned beaches, and it drained eastward by the Mohawk to the Hudson, since the St. Lawrence region was still covered by ice. Another line of drainage was along the present channel, past Detroit, to Lake Erie and by the new-formed Niagara (see p. 760, Pt. I) to Lake Iroquois. Still further melting back of the ice-front uncovered the Ottawa River and the St. Lawrence, and the upper three lakes, now somewhat shrunken to form the Nipissing Great Lakes, drained along this line to the St. Lawrence which, because of the depression of the land, had been inundated by the sea, as

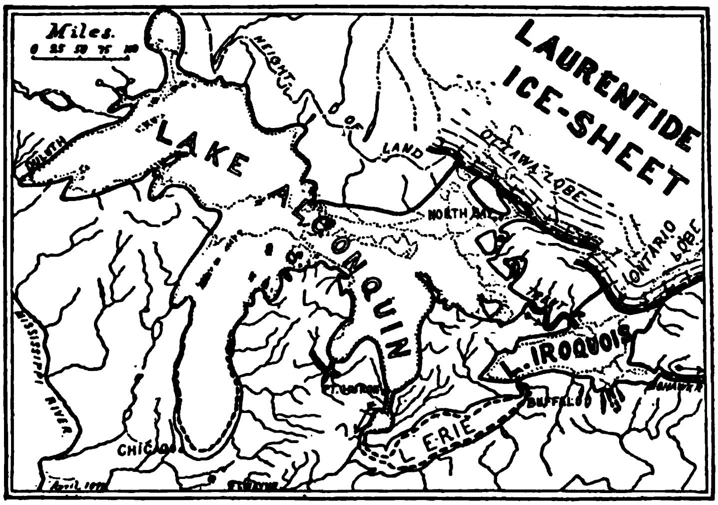


FIG. 1930. — Map of Lake Algonquin, the predecessor of the Great Lakes. (After Taylor.)

shown by the presence of marine fossils, including the skeleton of a whale in the old beaches. This marine invasion extended, on the one hand, across the ancient Thousand Island divide, into the Ontario basin, and on the other, into the Champlain Valley east of the Adirondacks, converting these bodies into inland salt bays (Fig. 1931). The evidence of this former marine invasion is still preserved to some extent in the faunas and floras of these basins and of their margins. Lake Erie drained separately to Ontario by way of the now diminished Niagara, as already outlined (pp. 769–770, Pt. I). Finally, by the rise of the land in the north, the Ontario channel was abandoned; the sea withdrew from the St. Lawrence-Champlain basin, and the present drainage was established.

Lake Agassiz. — In North Dakota, Minnesota, and Manitoba, Canada, there is a broad, flat-bottomed valley drained north-

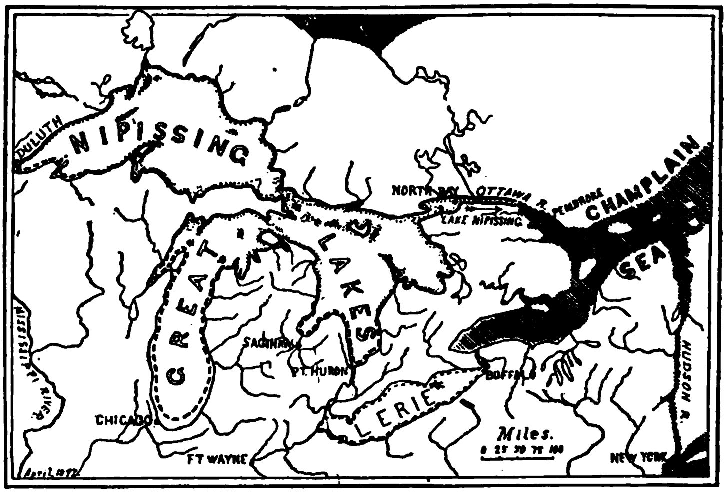


FIG. 1931. — Map of Nipissing Great Lakes and the Champlain Sea. The outlet of the Great Lakes is by the Ottawa River. (After Taylor.)

ward by the Red River of the North, into Lake Winnipeg and thence into Hudson Bay. As the melting ice-sheet uncovered this basin, but still formed a barrier across it on the north, the depression in front of the ice was filled with water to the level of the lowest outlet in the southern rim of the basin, across which

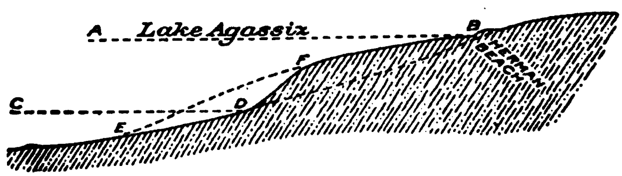


FIG. 1932. — A delta in glacial Lake Agassiz. (U. S. G. S.)

it discharged into the Missouri and the Mississippi. This glacial-dam lake, in which many deltas and terraces were formed (Fig. 1932), and which during its maximum stage had an area exceeding that of the Great Lakes combined, has been called Lake Agassiz, in honor of the great Swiss-American naturalist, Louis

Agassiz (portrait, *ante*, p. 54, Fig. 775), to whom we owe the development of the theory of extensive Pleistocene glaciation. The present remarkable flatness of this valley bottom is due to the fact that sands and silts, carried into the lake by streams, were spread over the floor, smoothing out all inequalities.[1] It is now one of the richest wheat-growing districts in the world.

Other Ice-dam Lakes. — Ice-dammed lakes of the type of Märjelen Lake of to-day (*ante*, p. 361, Pt. I) came into existence whereever the slope of valley bottoms was against the ice-sheet which formed the dam across the lower end of the valley. Then the water rose to the lowest notch in the margin across which it could drain, and at this level beaches and deltas were commonly built. As lower outlets across the rim were uncovered by the melting ice, the surface of the lake sank to a corresponding level and lower beaches and deltas were formed. It is by these beaches and deltas, the character of which has already been explained (p. 503, Pt. I), that the successive levels of such a fluctuating lake are determined. In Massachusetts a number of such extinct lakes have been mapped and named. Among these are *Lake Bouvé*, south of Boston, *Lake Charles*, in the valley of the Charles River, *Lake Nashua*, farther to the north, and *Lake Bascom*, in northwestern Massachusetts, this lake standing at a maximum elevation of 1100 feet above the present sea-level and sinking successively to levels of 1000, 900, 700, and 600 feet, until it was finally drained by the uncovering of the present outlet of the valley by the Hoosic River. In New York State many such lakes existed in the valleys now occupied by the Finger-Lakes and in the Genesee and other valleys. These drained southward, having usually only a single outlet at their southern end, and completely disappearing as the ice barrier on the north melted away. The complex history of the valleys occupied by the Genesee River system has already been outlined (pp. 775–785, Pt. I). In New Jersey, too, such an extinct glacial lake, *Lake Passaic*, has been discovered.

Lakes in Embayments of the Ice. — Where, by unequal melting of the ice-sheet, either along the front or on the sides of a glacial mass which occupied a valley, embayments were formed in the ice, these gave rise to temporary lakes, the levels of which were determined by the outlets, either to another drainage-system, as in the

[1] For details of this extinct lake, see Warren Upham: "The Glacial Lake Agassiz," Mon. U. S. Geol. Sur., vol. 25, 1896.

modern Märjelen Lake; along the margin of the main body of ice, as is the case in certain low stages of Lake Märjelen; or across the moraine which formed part of the frontal barrier of the lake. One example of the latter has already been described in glacial

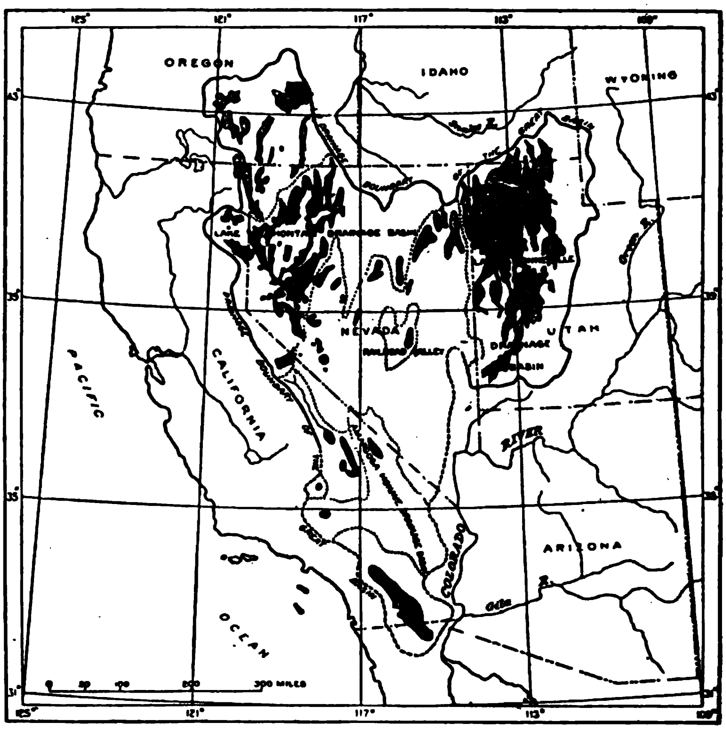


FIG. 1933. — Map showing outline of the Great Basin and the lakes which it once contained. Shaded areas show Quaternary lakes, dotted lines show boundaries of drainage basins. (U. S. G. S.)

Lake Shaler, in the several stages of which the sand-plains of Truro, Wellfleet, and Eastham on Cape Cod were deposited. Examples of lakelets, marginal to a residual ice mass which occupied a valley, are found in the valley of the Hudson River, and in these lakes various sand-plains now found along the margin of that valley were deposited.

Pleistocene Lakes of Enclosed Basins. — During the moister climatic conditions of the Pleistocene, lakes came into existence in basins of inland drainage, and these, in some cases, were filled until the water spilled across the rim of the basin at the lowest point. Such a water body was Lake Bonneville, which existed in western Utah in the basin now partly occupied by Great Salt Lake (Fig. 1933). At its maximum it was a thousand feet deep and 17,000 square miles in area. The various shore lines of this extinct fresh-water lake are distinctly marked by terraces along

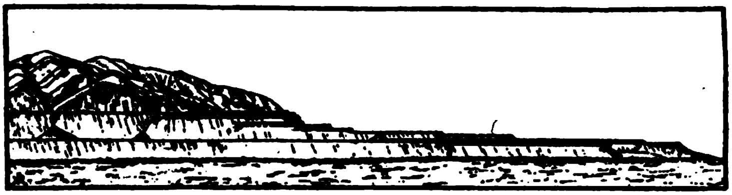


FIG. 1934. — Abandoned shore-lines and terraces of ancient Lake Bonneville. (After Gilbert.)

the sides of the mountains which enclose the basin (Fig. 1934; see also Figs. 176–177, p. 253, Pt. I). Another, though less continuous water body of this type, was Lake Lahontan in western Nevada, southern Oregon, and northeastern California (Fig. 178, p. 254, Pt. I). To-day a number of small saline lakes occupy the deeper portions of the basin, this lake, like Lake Bonneville, having been dismembered by evaporation.

OTHER PLEISTOCENE AND HOLOCENE DEPOSITS IN AND BEYOND THE GLACIATED AREA

Marine Deposits of the Atlantic Coast. — In Maine, and especially in the Champlain basin of Vermont, as well as on the Labrador and Greenland coasts, marine deposits are found, which were formed since the withdrawal of the ice from those regions. They now lie at elevations up to 600 feet above the sea. The fact that they are of post-glacial origin is shown by their relation to glacial deposits, such as drumlins which were cut into or cliffed by the sea in which these deposits were formed, and by their superposition upon the glacial till.

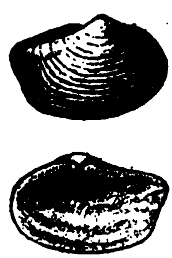


FIG. 1935. — *Yoldia* (*Portlandia*) *arctica*. (After Brögger.) Quaternary (*Yoldia* clays), Norway and Maine.

The best known of these are clays with shells of *Yoldia arctica* (Fig. 1935), *Leda* *pernula*, *Astarte*, *Mya*, *Buccinum greenlandicum*, and other cold-water mollusks (*Leda clays*) over which lie sands with the pelecypod *Saxicava arctica* (Fig. 1936) (*Saxicava sands*). These genera and species of mollusks are still living upon the northern Atlantic coast. It is evident that since the deposition of these clays and sands (Champlain submergence) the region has undergone an elevation carrying these old ocean bottom deposits to their

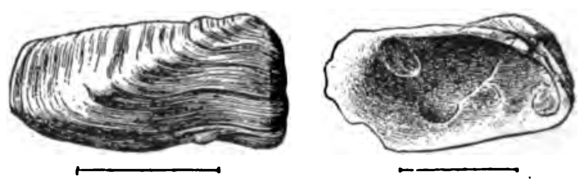


FIG. 1936. — *Saxicava arctica*, an arctic mollusk living in the North Atlantic to-day. The shells are also found in the high-level marine deposits of the glacial period. (I. F.)

present altitude. Other deposits of this kind, now above sea-level, are found on the Massachusetts coast (Nantucket Island, etc.) and elsewhere. In the Gulf of Mexico region, also, local elevation has taken place, bringing deposits of shells and coral reefs some distance above the sea-level, as on Porto Rico, Cuba, and elsewhere.

Interior Continental Deposits. — In the southern United States and in Mexico and Central America, continental deposits were formed during the Quaternary era, partly by rivers, but also in swamps, in asphalt pools, in caverns, and elsewhere. These commonly include the remains of the Pleistocene and more recent land and fresh-water animals and plants. Older deposits of this type have been found in Florida (Peace Creek), Nebraska (Loop Fork, Hay Springs), Texas (Rock Creek), Oregon (Silver Lake), and Kansas. By some authorities, most or all of these deposits are classed as youngest Pliocene. Undoubted Quaternary bog, pool, and cavern deposits are, however, found on the Pacific border, in South Carolina, and in Pennsylvania, and younger deposits still in the famous Conard fissure of Arkansas. Extensive accumulations of this age, characterized by mammalian bones, are also found in the high valleys of Mexico, although some of these have been classed as late Pliocene. Analogous deposits are found in Ecuador, Brazil, Bolivia, and the Argentine Republic, where, especially in the great series of sands and clays of the Pampas, a rich harvest of the remains of the great Quaternary mammals, such as the *Megatherium*, *Glyptodon*, horses, mastodons, etc., has been secured.

The Loess of the Mississippi Valley. — Finally, we must note the rather wide distribution of loess in the Mississippi Valley, especially in Illinois, Iowa, Nebraska, and more southern states. The nature

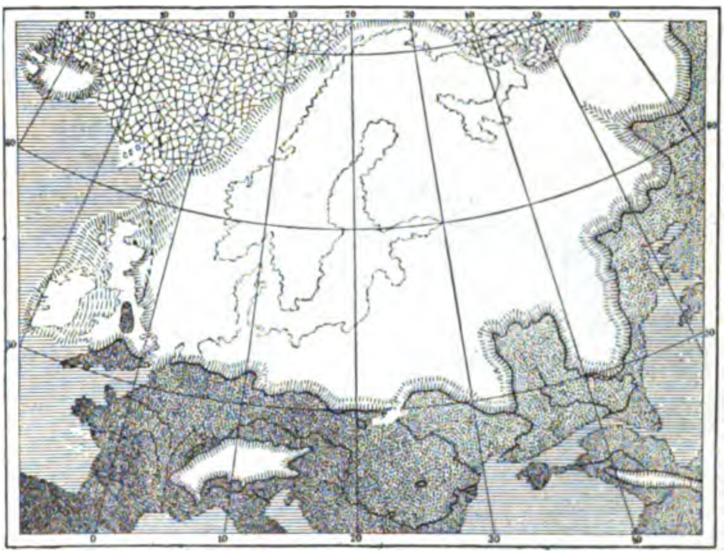


FIG. 1937. — Map of Europe during the greatest extent of the Pleistocene ice-sheet. (After de Geer from Kayser.)

of this deposit has already been explained (p. 458, Part I) and it is only necessary to state here that it apparently originated from the rock-flour of the glacial deposits, and was distributed by wind and locally by streams. Along the Mississippi and Missouri, as at Omaha and Council Bluffs, it forms vertical cliffs, similar to those formed by the Chinese loess. Its thickness seldom exceeds 50 feet, and generally it is much thinner. It contains locally the shells of land and, more rarely, fresh-water snails, and calcareous and iron-stone concretions.

The Quaternary of Europe

In Europe two distinct regions of ice accumulation are recognized, — the north European and the Alpine. The former was by far the larger, covering in its maximum extent all of Scandinavia and Finland and a large part of northwest Russia, on the one hand, and extending to the British Isles, on the other, covering them except southern England and southwest Ireland. Southward it extended to the 50th parallel of latitude (Fig. 1937). The alpine glaciation spread for some distance in all directions from the

Fig. 1938. — Map of the Alps during the Glacial period. Ice in black; heavy black lines are terminal moraines of the latest glaciation. (After Kayser.)

Alps, but did not become confluent with the northern ice-sheet (Fig. 1938). Many small glaciers existed upon other European mountain peaks, but these were of local significance only.

Besides the glacial and interglacial deposits, there are certain marine Quaternary sediments which have since been exposed to view, and there are extensive fresh-water and cavern deposits as well. Europe is, moreover, favored in having a definite succession of human culture stages which extended through the greater part of the Quaternary, these being especially known from France and other south European countries which lay outside of the glaciated area. The following table gives a general view of the subdivision of the European Quaternary.

TABLE OF THE SUBDIVISIONS OF THE QUATERNARY OF EUROPE; ITS CULTURE, HUMAN RACES, AND APPROXIMATE TIME PERIOD. (After Haug, Osborn, and others)

SYSTEM	GLACIAL AND INTERGLACIAL STAGES		HUMAN CULTURE STAGES AND RACES — CHIEFLY IN EUROPE	LOCATION	TIME B.C. (Approximate)
Upper Quaternary Recent or Holocene (Holocenic)	Post-Glacial Stages		VI. Age of steam and electricity	Europe	Roman to modern
			V. Later Iron Age (La Tène Culture)	Europe	500 B.C. to Roman time
			IV. Earlier Iron Age (Hallstatt Culture)	Europe Orient	1000–500 B.C. 1800–1000 B.C.
			III. Bronze Age	Europe Orient	2000–1000 B.C. 4000–1800 B.C.
			II. Neolithic or New Stone Age		
			3. Late Neolithic and Copper Age (Transition Period)	Europe	3000–2000 B.C.
			2. Typical Neolithic Age, (Robenhausian, Swiss Lake Dwellers) . . .	Europe	7000 B.C.
			1. Early Neolithic Age (Campignian Culture)	Europe	
Middle Quaternary Pleistocene or Pleistocenic proper			I. Palæolithic or Old Stone Age. Upper Palæolithic		
	6th Glacial	Upper Turbarian	8. Azilian-Tardenoisian — Grenelle race	Europe	12,000 B.C.
	5th Interglacial	Upper Forrestian	7. Magdalenian — Crô-Magnon and Grimaldi races	Europe	16,000 B.C.
	5th Glacial	Lower Turbarian	6. Solutrean — Crô-Magnon and Grimaldi races		
	4th Interglacial	Lower Forrestian	5. Aurignacian — Crô-Magnon and Grimaldi races Lower Palæolithic		
	4th Glacial	Würmian (Mecklenburgian)	4. Mousterian — Neanderthal man	Europe	40,000 B.C.
			3. Acheulean — Neanderthal man	Europe	75,000 to 50,000 B.C.
	3d Interglacial	Chellean or Neudeckian	2. Chellean	Europe	100,000 B.C.
			1. Pre-Chellean (Mesvinian) — Piltdown man	Europe	125,000 B.C.
	3d Glacial	Rissian or Polandian	Late Eolithic		
Lower Quaternary Early Pleistocene or Post-Pliocene			Early Eolithic		
	2d Interglacial	Cromerian or Helvétian	Pre-Cultural Stages . . . . Heidelberg man	Europe	360,000 to 200,000 B.C.
	2d Glacial	Mindelian or Saxonian (Sicilian = marine)	. . . .	Europe	410,000 to 360,000 B.C.
	1st Interglacial	Saint-Prestian or Norfolkian	. . . .	Europe	475,000 to 410,000 B.C.
	1st Glacial	Villafranchian, Günzian or Scanian (Calabrian = marine)	. . . . Pithecanthropus or Trinil race	Europe and Orient	510,000 to 475,000 B.C.

In the east of England (Norwich Crag, Chillesford Clay, Weybourn Crag) occur marine beds of the older Quaternary which contain an assemblage of mollusks of which about eleven per cent of the species are extinct. On this account they are still classed with the late Pliocene, but according to Haug and others they are contemporaneous with the early glacial and interglacial stages of the Continent. They continue the succession of Pliocene beds formed in overlapping series on the borders of the North Sea before the ice from Scandinavia reached the English coast, which was only after the deposition of the *Cromer forest-beds*, these being regarded by some geologists as equivalent to the second interglacial epoch. These *Cromer* forest-beds, which overlie the Weyborn Crags, are partly marine, with *Yoldia*, and partly terrestrial with fresh-water beds, including a deposit of tree trunks and roots, and terminated by a bed with Arctic plants. It is quite evident that glacial conditions in the British Isles began later than they did on the Continent. Such older Quaternary marine beds, sometimes intercalated between glacial beds, are found on the Scandinavian and Netherlands borders of the North and Baltic seas. Similar marine incursions are also found in the Middle Quaternary, thus showing that the country was sufficiently depressed locally to permit the transgression of the sea whenever the ice-sheet shrank by melting. For the most part, the organisms in these deposits are cold-water forms, most of them of types which still exist in the northern seas. This was especially the case in the Baltic during the later glacial epochs, when this water-body was not only connected with the North Sea along its present outlet, but with the Arctic Ocean as well, across eastern Finland and Russia. This was the period of the *Yoldia Sea* (Fig. 1939). In the early Upper Quaternary, or Holocene, marine deposits were still forming upon the Scandinavian coast of the North Sea, but the Baltic had become a cut-off and was converted into a fresh-water lake, the *Ancyclus Lake* (Fig. 1940), so called from the presence in abundance of a minute fresh-water gastropod (*Ancyclus fluviatilis*), besides many others, such as *Paludina*, *Planorbis*, *Limnæa*, etc. (see Fig. 773, p. 52) in the now exposed marginal deposits. This period was followed by a partial reinvasion of the sea in which lived the modern gastropod *Littorina littorea* (*Littorina Sea*). This also covered portions now land and in it marine, brackish, and fresh-water forms were, to some extent, commingled. Finally, the modern conditions became established.

In the Mediterranean basins, marine and fresh-water deposits likewise characterized the Quaternary, the former often extending over regions now land. Such was the case in the Rhine Valley region and in southern Italy, Sicily, the Balearic Islands, and the north African coast, where two marine series, the *Calabrian* and the *Sicilian*, are recognized and correlated approximately with the first and second glacial epochs, though often also included as late Pliocene (see Fig. 1859, p. 820). The typical *Villafranchian* of the Apennines is a fresh-water deposit. Marine conditions also prevailed to some extent in the Aralo-Caspian basin and in that of the Black Sea.

Beyond the borders of the ice-sheets, extensive fluviatile deposits were formed in the river valleys and these contain the remains of

FIG. 1939. — Palæogeographic map of northwestern Europe in late glacial time, showing the *Yoldia* sea. (White represents melting ice-cap.) (After Kayser.)

FIG. 1940. — Palæogeographic map of northwestern Europe in post-glacial time, showing the *Ancylus* lake. (White represents melting ice-cap.) (After Kayser.)

the land animals of the periods and, to some extent, those of man, including his implements as well. The most satisfactory record of man's existence in the Quaternary is, however, found in the caves and the deposits of the culture stations, preserved in place, and which have been little disturbed since their deposition. Over wide areas in Europe as well as Asia, deposits of loess were formed from wind-transported dust, largely derived from glacial material. Finally, extensive peat-deposits accumulated in the northern portions of Europe as they did in America.

THE CAUSE OF GLACIATION

What brought about the refrigeration of the climate in North America and in Europe, which permitted the accumulation of these great ice-sheets in Pleistocene time? If we can solve this question of the last great glaciation in the history of the earth, we shall probably obtain a key to the more remarkable glaciation which occurred in Permian time and earlier in the equatorial regions of the earth; for the conditions which produced one were probably operative in the others as well, though additional causes may have obtained during the older glacial periods. A number of hypotheses have been advanced to explain the glaciation in Pleistocene time, but none of them appear to be wholly satisfactory. We may briefly review the more important ones.

Terrestrial Causes

Extensive Emergence of the Lands. — It is a well-known fact that the interiors of large continental masses are subject to greater extremes of climate than are the coastal regions or small land masses surrounded by the ocean. This is illustrated by the mean annual range in temperature of two localities, both lying in 62° N. latitude. One of these, Thorshaven, on the Faroe Islands, has a mean annual range of 7.9° C., the March mean being + 3.0° C. and the July mean + 10.9° C. The other locality, Yakutsk, in central Siberia, has a range of 61.6° C., from a mean of − 42.8° C. in January to + 18.8° C. The vastly greater cold of such a widespread continent might favor the accumulation of an excess of snow and ice to a degree sufficient to prevent its complete removal during the warmer summer months, but it is extremely doubtful if this would go on to the extent required for the formation of the great Pleistocene ice-sheets, unless there were a simultaneous lowering of the temperature as a whole which, while not affecting the range, would depress the degree of both extremes to a very considerable extent. Moreover, such emergence of the continents would not explain why the Pleistocene glaciation was practically confined to the Western Hemisphere (in North America and northern Europe) while Asia, the largest continent then, as now, was unaffected by glaciation except locally in mountain regions. Again, it should be noted that the lands of North America were probably little more extensive in Pleistocene time than they are to-day, and yet no glacial conditions exist there at present. Moreover, the glacial deposits of western Europe have intercalated marine beds between them, showing that the ice was extensively developed along the coast, as was also the case in eastern North America and in Greenland. Finally, expansion of the land alone would not explain the repeated alternate advance and disappearance of the ice with the spreading of much milder climatic conditions over the previously glaciated area.

Elevation of the Land.—That great elevation of the land locally produces glaciation is a well recognized fact, but the amount of elevation necessary varies in different latitudes and with atmospheric conditions. Thus Pikes Peak, in the Rocky Mountain Front Range, with a height of over 14,000 feet, has no permanent glaciers, while Mont Blanc, 7 degrees latitude farther north, and only about 1600 feet higher, is covered with them. The snow-line, or line of perpetual snow, in the Bolivian Andes, near the equator, lies at an elevation of 5500 meters (18,500 feet) on the west side and 4876 meters (16,000 feet) on the east side. In Lapland (lat. 70° N.) it lies at an elevation of about 915 meters (3000 feet) and in Greenland (lat. 60°–70° N.) at about 670 meters (2200 feet). The average for the lower limit of perpetual snow on the equator is about 4800 meters, while for lat. 40° it is about 3000 meters. Near the coast, or where much moisture is supplied, it is lower than in the dry inland regions.

But while elevation accounts for alpine glaciation, it does not enter into the problem of the continental glaciers which covered North America and Europe in Pleistocene time, for these, as we have seen, rested often at sea-level and, on the whole, accumulated in the low-lying country rather than the high.

Change in Ocean Currents. — Marine currents greatly modify the climate of the lands which border the oceans under their control. The mild climate of the coasts of Britain and northern France, which regions lie in the latitudes of Newfoundland and the Labrador coast, is due primarily to the northeastward set of the drift of the Gulf Stream, which is the northern branch of the warm equatorial current of the Atlantic, split in two by the projecting point of South America. If this current should be wholly deflected to the South Atlantic by some change in the conformation of the land or ocean floor, or a migration of the heat equator, a marked refrigeration of the northern lands would result. Whether this would be sufficient, however, to produce glaciation may be doubted.

Atmospheric Causes

Change in Volume of Carbon Dioxide. — During periods of extensive marine transgressions and the formation of limestones, either by chemical precipitation or by the physiological activities of organisms, the carbon dioxide content of the atmosphere is increased, because the extra molecule of CO_2, which holds the lime in solution in the sea-water, is liberated on the precipitation of the lime, and in part returns to the atmosphere. On the other hand, withdrawal of the sea, the spread of lands, and the extensive growth of vegetation tend to deplete the atmosphere of its CO_2 content, partly by carbonation of the rocks in weathering and by solution of limestones, and partly by its direct appropriation by plants. Now it is known that carbon dioxide, as well as water vapor, acts as a thermal blanket in the atmosphere to retain the sun's heat within it. Arrhenius has estimated that if the CO_2 content of the atmosphere were increased from 2.5 to 3 times its present volume, the temperature in the Arctic region would rise from 8° to 9° C., and produce a mild climate, such as that of Eocene time, when magnolias grew in Greenland. If, on the other hand, the content of CO_2 were decreased to an amount ranging from 0.62 to 0.55 of its present volume, a fall of from 4° to 5° C. would result and glacial conditions would again overspread the northern countries. Whether these figures are accurate or not, the general fact is established that the increase in CO_2 in the atmosphere produces milder, and its decrease colder, climates; but such climatic changes would be world-wide. Instead of the formation of glaciers in the northern parts of America and Europe, with centers of accumulation lying south of the pole, there should be a more or less uniform spread of glacial conditions in all directions, both from the north and the south polar regions, while the temperature conditions of the equatorial regions would be equally lowered. Asia and Alaska should, from the operation of this cause, be no freer from glaciation than Europe and eastern North America. Nor can the alternation of glacial and interglacial warmer epochs be correlated with spread of lands, on the one hand, and extensive marine submergences, on the other.

Excess of Volcanic Ash in the Atmosphere. — It has been shown (Humphreys) that when in volcanic eruptions much fine volcanic dust is shot into the upper atmosphere, where it may remain suspended for long periods of time, a blanket against the rays of the sun is produced and the temperature of the surface of the earth is correspondingly lowered. While this may be a contributory cause, it cannot be regarded as a primary one in the production of glacial climates, and the main objections cited against the carbon dioxide theory also apply here.

Astronomic Causes

Variations in Solar Energy. — It has been ascertained that the amount of heat given out by the sun is variable, the limits being within 5 to 10 per cent in quantity and in time periods ranging from 5 to 10 days. If such variations were extended over longer periods and were of sufficient magnitude to lower the temperature of the earth from 9° to 11° F., glacial conditions would again overspread North America and Europe, while a change in the other

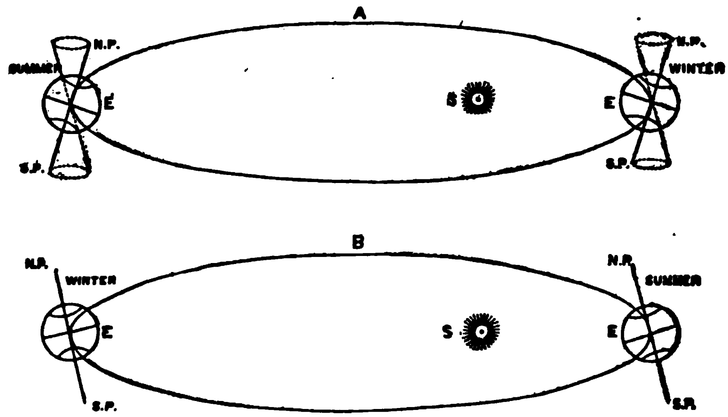


FIG. 1941. — Diagram showing the effect of precession: *A*, condition of things now; *B*, as it will be 10,500 years hence. The eccentricity is of course greatly exaggerated.

direction would bring with it a period of milder interglacial climate. It is difficult to see, however, why such a change would not affect Asia, at least to some extent, nor is there any evidence that the amount of variation and the persistence of such variation was great enough to produce the required results.

Precession of the Equinoxes (Croll's hypothesis) (Fig. 1941). — The earth's orbit, or the path it describes about the sun, is not circular but elliptical, with the sun at one of the foci. The inclination of the earth's axis is at present such that the earth is nearer to the sun by 14,000,000 miles in midwinter (perihelion) of the northern hemisphere, than in midsummer (aphelion). The path which it travels from autumn to midwinter and to spring is correspondingly shorter than the one it travels from spring to midsummer to autumn. But the earth undergoes a movement by which the inclination of the axis is changed to the opposite direction in the course of 10,500 years. This is called the "precession of the equinoxes." As a result, midwinter in the northern hemisphere would occur when the earth is farthest from the sun and had the longest path to travel between the autumnal and vernal equinoxes. It would be 22 days longer than now and 20° colder, while the summers would be 22 days shorter than now and correspondingly hotter. Croll has argued that this winter would allow an accumulation of snow and ice in excess of that which could melt during the summer, and the cumulative effect would produce glaciation. Such glaciation would, however, recur periodically every 21,000 years, provided this factor alone were responsible, and for such regular recurrence there is no evidence. Moreover, according to this hypothesis, the southern hemisphere should now suffer maximum glaciation, and this should alternate regularly with that of the northern hemisphere; yet there is evidence that the Antarctic ice was formerly more extensive than now, though this may not have coincided with the maximum glaciation of the northern hemisphere. Finally, glaciation produced in this manner should proceed from the polar region and extend in all directions, modified only by the local character of the continents.

Displacement of the Poles. — If we could assume that in Pleistocene time the earth had a different relation to its axis so that the north pole was 15 degrees or so farther south, lying approximately in the center of Greenland, conditions favoring the glaciation of North America and northern Europe would be furnished without invoking an extensive general reduction of the earth's climate. This would also account for the relative freedom of Asia from glacial conditions at that time (Fig. 1942).

Such a change in the position of the poles would, of course, imply a corresponding change in the position of the equator, which would be 15 degrees farther south in the region of eastern Brazil, and 15 degrees farther north in the western Pacific. An apparent confirmation of the hypothesis, that this condition existed in Pleistocene time, has been obtained by the finding of Pleistocene Mollusca, in southern Japan, of species now at home on the Philippine coast, 15 degrees farther south. The corresponding northward shifting of the south pole would account for the glaciation of southern Australia, Tasmania, and New Zealand, but not for that of Patagonia, if this occurred at the same time.

Astronomers and geophysicists have, however, denied the possibility that with an earth as rigid as ours, such a shifting of the

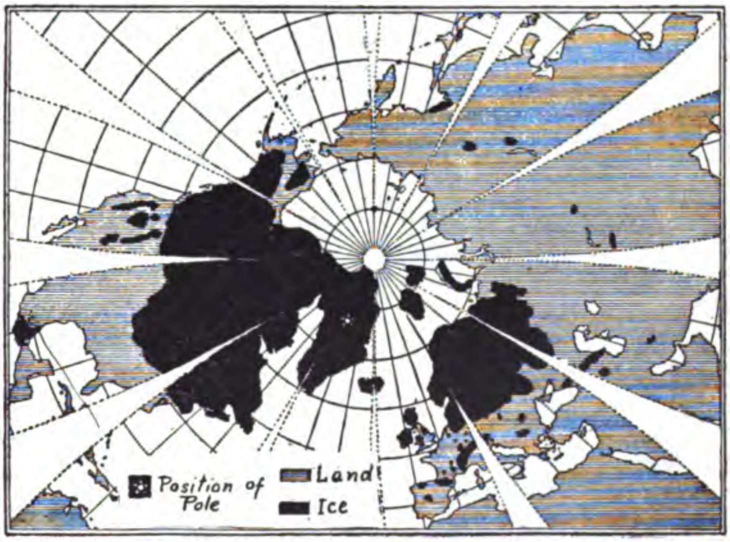


FIG. 1942.—Map of the distribution of the Pleistocene ice-sheet in North America and Europe, and the explanation of glaciation on the hypothesis of the shifting of the poles. The location of the North Pole on this hypothesis is indicated by a star. (Modified from Walther.)

poles is possible, despite the fact that minute wanderings of the poles have been determined from changes in latitude within historical time. At present, this explanation of the Pleistocene glaciation must be regarded as purely hypothetical, though extremely suggestive.

CHAPTER XLVIII

LIFE OF THE PSYCHOZOIC OR QUATERNARY ERA — THE ANCESTRY OF MAN

The Quaternary invertebrate and plant life is essentially the life of the present, except that in the early Pleistocene, in beds which are referred by some to the late Pliocene of the Tertiary, there still occur some mollusks (about 11 per cent) and other invertebrates which have since become extinct so far as the species are concerned. A greater difference between the life of the Pleistocene and the present or Holocene is seen in the vertebrates, especially in the mammals and in man. A number of species of large animals have become extinct since the dawn of the recent or Holocene period, among them the moa (*Dinornis*, Fig. 1943), a giant bird which lived in New Zealand, the urochs (*Bos primigenius*, Fig. 1955), and many others.

FIG. 1943. — The extinct moa or *Dinornis* of New Zealand. (From Lyell.)

THE PLEISTOCENE MAMMALS

The remains of these are found in river gravels, in deposits of volcanic dust and other eolian sediments, in peat-bogs, swamps, playa lakes, caves (Fig. 1944), etc., but seldom in marine deposits. Special cases of preservation of Pleistocene mammals are seen in the tar pool of California, and in the frozen tundra of Siberia, where the skin and flesh of the animals have sometimes been preserved.

Among the **carnivores**, foxes make their first appearance in America in Pleistocene time. Here they split into two groups, one

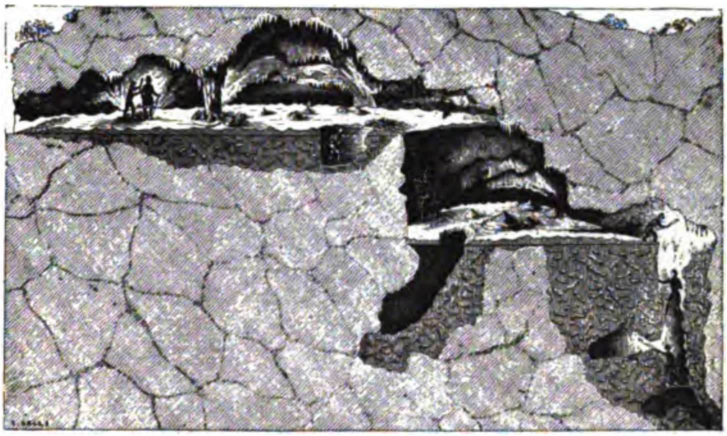


FIG. 1944. — Vertical section through Gailenreuth cavern, Franconia, showing bone-breccias. Many hundreds of skeletons of extinct bears and other Pleistocene mammals have been obtained from this cavern. (After d'Orbigny.)

retaining the essential characters of the European red fox (*Vulpes*), the other becoming the American gray fox (*Urocyon*). Wolves, too, returned to America, the home of their ancestors, in Pleisto-

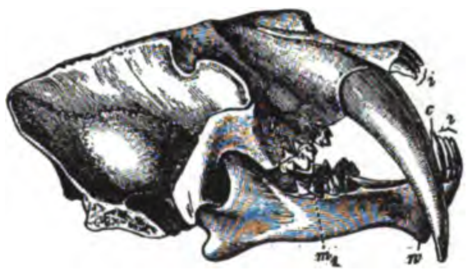


FIG. 1945. — Skull of the saber-tooth tiger (*Smilodon neogæus*), Pampas clay, Argentina; *w*, prolongation of the symphysis of the lower jaw; m_1, p_4, carnassial teeth; *c*, lower canine; *i*, incisors. Reduced. (From Steinmann.)

cene time (Fig. 1947), but the domestic dog was introduced in modern times by man. The cat tribe was represented by the giant saber-tooth, *Smilodon* (Figs. 1945, 1947), in America, and by another form, *Machærodus* (Fig. 1946), in Europe, where it was

FIG. 1946. — Restoration of the saber-tooth tiger (*Machærodus*) from the Middle Pleistocene of western Europe. This was one of the many mammals which survived from the Upper Pliocene and which was a contemporary of the Pleistocene deer, moose, elephants, carnivores, and primitive cattle. (Courtesy of American Museum of Natural History.)

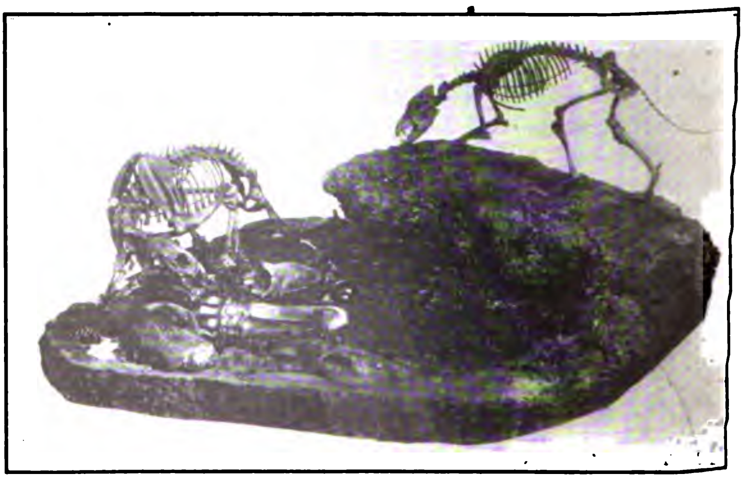


FIG. 1947. — Restoration of the Rancho La Brea, California, a water pool with asphaltic margin and tar oozing out in many places. This pool formed a natural trap in which Pleistocene birds and mammals were caught, their bones being preserved in a but slightly altered condition. On the right is a wolf (*Canis dirus*), in the foreground a sloth (*Paramylodon*) mostly sunk beneath the surface of the pool, and to the left, the saber-tooth tiger (*Smilodon californicus*). (Photograph of group in American Museum of Natural History, by courtesy of that Institution.)

the contemporary of early man. *Smilodon* is apparently a pure American type and spread all over the United States. Its peculiarities seem to have developed in conformity with its habits as a hunter of the giant sloths, the *Megatherium* and *Mylodon*, which it followed in their migrations from South to North America. In the famous Port Kennedy Cave, on the right bank of the Schuylkill River, two miles below Valley Forge in Pennsylvania, the remains of this saber-tooth have been found, together with those of the mastodon, tapir, ground sloth, bear, lynx, fox, prairie wolf,

FIG. 1948. — *Megatherium americanum*, about one-fiftieth natural size.

badger, deer, horse, bison, squirrel, rabbit, mole, shrew, bat, and so forth. Of the sixty-four species of animals whose bones had been swept into this cavernous fissure, twelve have living representatives, but the others have become extinct.

Another wonderful bone bed of this period occurs on the Rancho La Brea, about nine miles west of Los Angeles (Fig. 1947), California. Here a pool of sticky tar, formed by petroleum springs, entrapped the animals of the period. Among these were the California *Smilodon* and its prey, the Nebraskan ground sloth, *Paramylodon*, together with the bones of giant wolves, bears, tigers, and coyotes, of horses, bisons, mammoths, and camels, all of which lived in America in Pleistocene time. Birds, too, were swallowed

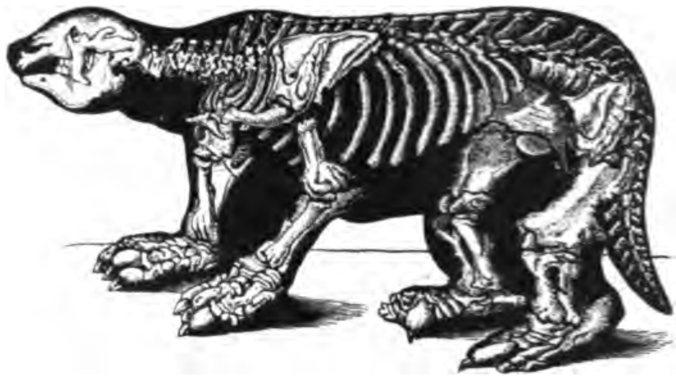


FIG. 1949. — *Megatherium cuvieri.* (After d'Orbigny.)

in this pool, no less than 33 individuals of the golden eagle having been found, together with the remains of herons, ravens, and the Canada goose. Even a peacock, a group of animals now restricted to the oriental region of southern Asia, is included in this remarkable burial ground of America Pleistocene animals.

FIG. 1950. — *Mylodon robustus.* (After d'Orbigny.)

Most remarkable of the extinct Pleistocene animals are the huge ground sloths or megatheres, *Megatherium* (Figs. 1948, 1949), *Mylodon* (Figs. 1950, 1951), and *Lestodon* (Fig. 1951), and the equally grotesque tortoise armadillos (*Glyptodon*, Fig. 1952, *Panochthus*, Fig. 1953, etc.). The megatheres were, for the most part, huge, clumsy creatures of slow, ponderous gait, and with a thick hide which only the dagger-like canines of the saber-tooth could penetrate. They fed on leaves, the young shoots of trees, and on other vegetation.

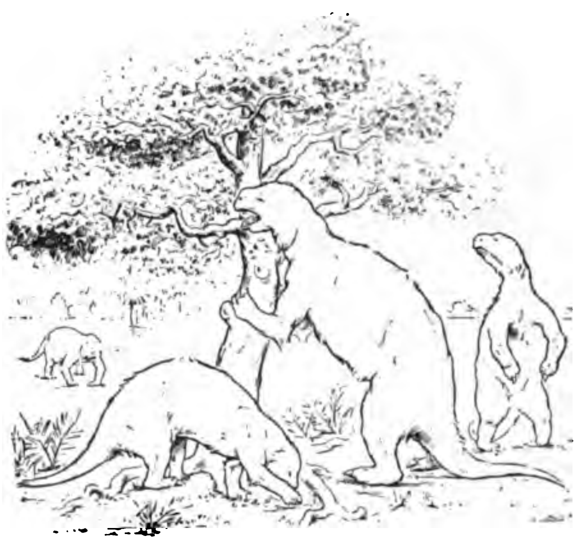


FIG. 1951. — A group of the great extinct South American ground-sloths, *Mylodon* and *Lestodon*, showing characteristic attitudes and mode of feeding. Outline restoration from a group of skeletons mounted in the American Museum of Natural History. (By courtesy of the afore-mentioned institution).

Originating in South America in the Miocene, the mylodons wandered into North America in the Pleistocene, as did also their descendants, the megatheriums.

Camels still lived in North America in the Pleistocene, during

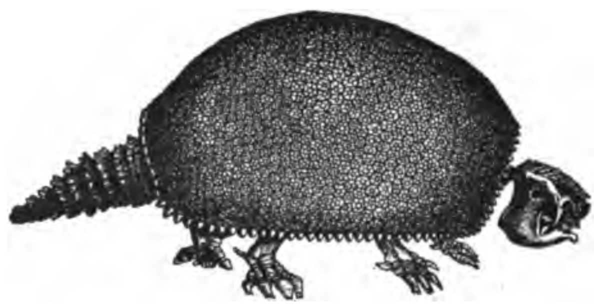


FIG. 1952. — *Glyptodon reticulatus*. Pampas formation, Argentine. Skeleton, $\frac{1}{60}$th natural size. (After Steinmann.)

which period they migrated to Asia, where they survive to the present day. The American camels became extinct in Pleistocene time from causes still unknown, though their humpless descendants,

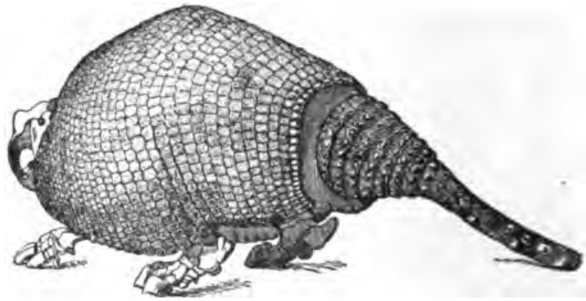


FIG. 1953. — *Panochthus tuberculatus*, a glyptodont from the Pleistocene deposits of the Argentinian Pampas. About $\frac{1}{40}$ natural size. (After Kayser.)

the auchenias or llamas of South America, have survived. Cattle are not native to America, except the American buffalo or bison, which came to America and to Europe in Pleistocene time and in each country developed a number of species, all of which became extinct except *Bison americanus*, with us, and *Bison bonasus*, in Europe. In the Pleistocene at least seven species of *bison*, some with enormous horns, roamed the American plains from Alaska to Florida. In Europe, *Bison priscus* (Fig. 1954), the ancestor of the modern European *Bison* or aurochs and a contemporary of early man, lives only in legend, as does the Urochs or *Bos primigenius* (Fig. 1955), which still lived in Germany in the 12th century and was probably the collateral ancestor of the modern long-horned cattle of western Europe. The true buffalo is an Asiatic type, living in India to-day, and apparently never migrated to America. In the Pleistocene an ancestor (*Bubalos antiquus*) wandered into North Africa, but has since become extinct. Of this animal Osborn says, "This was a powerful beast, which presumably lived in

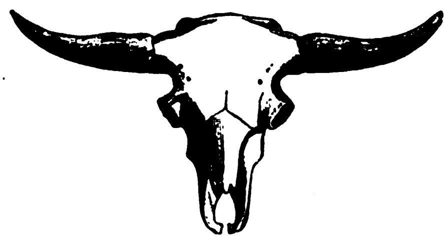


FIG. 1954. — Primitive cattle. The "aurochs" or Wisent, *Bison priscus* ($\times\frac{1}{18}$). Quaternary. The ancestor of the modern *Bison* (*B. bonasus*) of Lithuania, which is the true aurochs. (K.)

herds, frequenting grassy plains and swampy districts, and in its presence here we seem to find confirmation of what geology

FIG. 1955. — Primitive cattle: the "Urochs" (*Bos primigenius*) (×$\frac{1}{35}$). Quaternary. A collateral ancestor of the larger, long-horned, existing cattle of western Europe. The "*urus*" of Cæsar, which survived in Germany until the twelfth century. (K.)

teaches us in regard to the dampness of the Quaternary climate. The disappearance of the buffalo from North Africa at the com-

FIG. 1956. — The living musk-ox (*Ovibos moschatus*), a species which has survived from the Pleistocene.

mencement of the Recent Period was no doubt due to the increasingly dry conditions and partly to destruction by man."

Many other types of horned cattle existed in the Old World in Pleistocene time, and some have living descendants in the Asiatic regions. One of them, the musk-ox (*Ovibos moschatus*, Fig. 1956),

FIG. 1959. — Restoration of the woolly rhinoceros (*Rhinoceros antiquitatus*), the remains of which were found frozen into the mud and ice of the Siberian tundra. (Courtesy of American Museum of Natural History.)

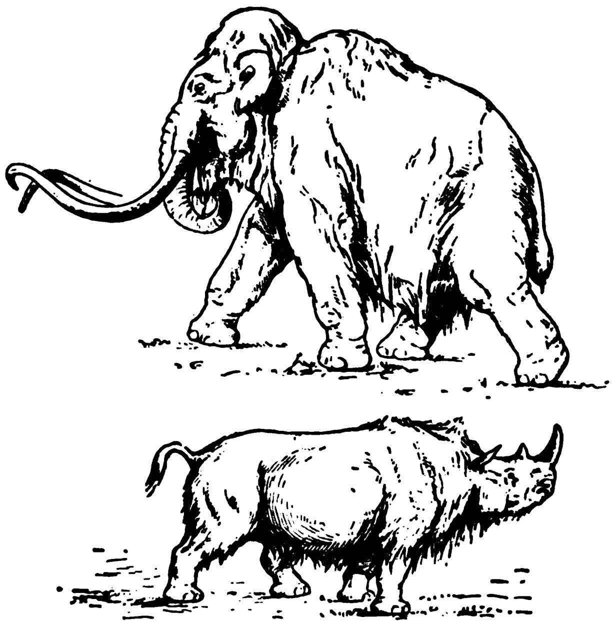


FIG. 1960. — Restorations of two of the tundra mammals, the woolly rhinoceros (lower), made known from the drawings of Upper Palæolithic artists and from an actual specimen discovered in Galicia, Austria; and the woolly mammoth (upper). (Courtesy of American Museum of Natural History.)

deposits, these animals, which survived even the first glacial advance, soon after became wholly extinct in the New World, but continued in Asia and Africa, whence they had migrated from North America in late Pliocene time. What caused the great extinction

FIG. 1958. — The extinct Irish elk (*Cervus megaceros*). (After d'Orbigny.)

of American horses is at present unknown. The cold of the glacial period was, no doubt, a partial cause, but this did not affect South America, where the horses also became extinct. It is possible that migrant animals from other lands brought in diseases which, like the sleeping-sickness of Africa and the Surra disease which attacks domestic horses in India, were transmitted by insects (Lull).

The rhinoceros became extinct in America before the end of Tertiary time, but continued in Europe during the Pleistocene, where it was represented by the giant one-horned elasmothere, the Etruscan rhinoceros, and the two-horned woolly rhinoceros (Fig. 1959), companion of the hairy mammoth and contemporary of

America in Pliocene time, and the Pleistocene witnessed their extensive migration over all parts of this country and also their

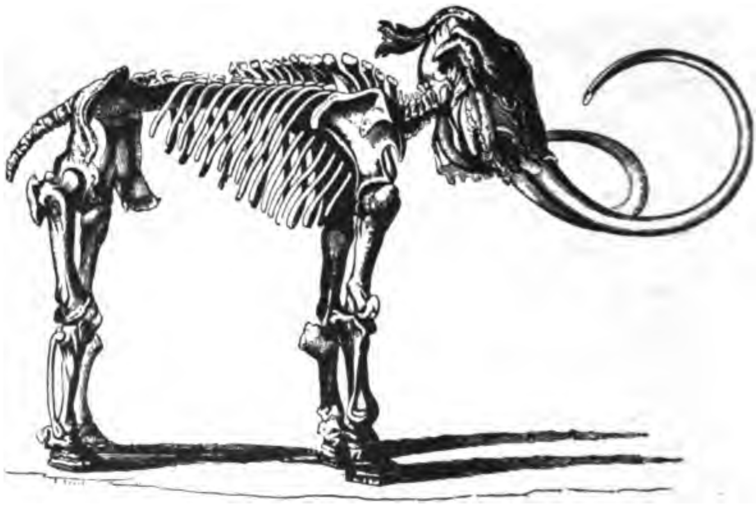


FIG. 1963. — Skeleton of mammoth (*Elephas primigenius*). (After d'Orbigny.)

FIG. 1964. — The woolly mammoth (*Elephas primigenius*) as depicted by Upper Palæolithic artists and from specimens found frozen in the tundras of Siberia. The mammoth was a contemporary of *Homo neanderthalensis* during the fourth glacial period. (Courtesy of American Museum of Natural History.)

total extinction here and in Europe, while again Africa and Asia proved the asylums in which the last survivors of these great pachyderms were preserved. The bones of the mastodon are found in many Quaternary deposits in North America (Figs. 1961, 1962).

While the ice-sheets covered North America and Europe, the hairy mammoth (*Elephas primigenius*, Figs. 1963, 1964), fitted to withstand the cold by virtue of its coat of coarse black hair lined underneath by thick brown wool, ranged the borders of the ice and

FIG. 1965. — Grinding teeth of: (*a*) mammoth, and (*b*) mastodon. (After Lucas, from Matthew.)

the ice-free regions of the far North. In the frozen tundras of Siberia its remains were found preserved with hair, skin, and flesh intact, and from these famous cold storage specimens the anatomy of this extinct animal has become well known. Other mammoths or giant elephants ranged over the open country farther south, while the more thickly forested country was inhabited by the mastodons, which outlived the true elephants in North America, but finally became extinct as did their South American relative, the *Dibelodon*.

MAN

The cradle of the human race has been placed by tradition in Southern Asia, and geological discovery bears out this tradition. The oldest known man-like creature was, however, not the highly endowed occupant of the traditional Garden of Eden, but a brute-like man not far removed from his simian ancestors. Neither the fossil nor the existing great apes show evidence of *direct* relationship to man, but their structure furnishes strong evidence of their descent from the same ancestral stock from which the earliest man-like creature was derived.

Early Races

The Trinil Man (Pithecanthropus erectus) (Figs. 1966–1968). — This, the early erect ape-man, was discovered by the Dutch army

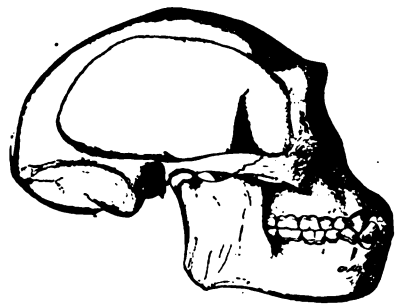


FIG. 1966. — The upper part of the skull of the Java or Trinil ape-man (*Pithecanthropus erectus*), found in the Siwalik sands of Java. (After Du Bois, from Alsberg.)

surgeon, Eugène Dubois, in 1891, near the village of Trinil in central Java, in deposits now regarded as contemporary with those made during the first glacial period of Europe, and antedating our present era by more than 475,000 years.

The remains first found by Dubois consisted of a single upper molar tooth and, three feet removed from this, the top of the skull. Later on, some 45 or 50 feet removed from the finding-place of the skull, he discovered a second molar tooth and a left thigh bone. Sixteen years later a left lower molar tooth of human type was found in these deposits. These remains, few and fragmentary as they are, made it possible to reconstruct the essentials of the creature and to demonstrate its primitive human character.

FIG. 1967. — Profile view of the Java ape-man. The skull and a thigh-bone were found by Dubois in 1891 and were described as *Pithecanthropus erectus*, referring to the fact that the ape-like man walked erect. The age of the beds in which these earliest remains of man were discovered is late Pliocene or early Pleistocene, probably the former. (After a model by J. H. McGregor. Courtesy of American Museum of Natural History.)

The skull is remarkable because of the low forehead and large ridges above the eye sockets (Fig. 1966). Its brain capacity is about two-thirds that of modern man, but much larger than that of the existing great apes, being about intermediate between the two (Fig. 1969). The retreating brow shows that the frontal lobes of the brain, the seat of the higher intellectual faculties, were still undeveloped, and that in consequence the creature had only a limited ability to profit by experience and tradition, while at the same time its powers of touch, taste, and vision were well developed. The teeth are more human than those of the gibbon, among the higher apes, but still retain some

FIG. 1968. — The left thigh-bone of *Pithecanthropus erectus*, found near the skull shown in Fig. 1966. (After Du Bois, from Alsberg.)

ape-like characters. The thigh-bone is slightly curved, and its character indicates an upright walking creature about 5 feet 7 inches in height (Fig. 1968).

The Heidelberg Man (Homo heidelbergensis) (Fig. 1970). — The next oldest fragment of a human skeleton is the jaw-bone of the

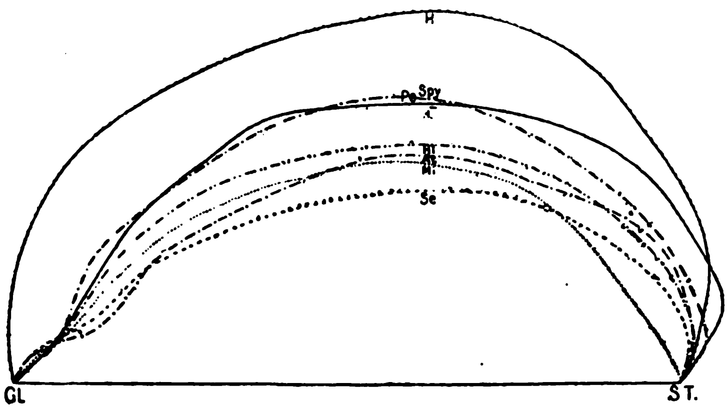


FIG. 1969. — Outlines of the cranidium or upper part of the skull of *Pithecanthropus*, and of apes and primitive men (from Alsberg). The types represented are: *H*, Papua; *Pe*, Pithecanthropus; *Hl*, Man of Spy; *At*, Troglodytes; *Se*, Semnopitheticus; *Mi*, Microcephalic; *Gl*, Glabella; *ST*, Transverse sulcus.

Heidelberg man, *Homo heidelbergensis*, called also *Palæanthropus heidelbergensis*, which was found in 1907 near Heidelberg, Germany, in river sands 79 feet below the surface. These deposits belong to the second warm or interglacial epoch, which followed the second ice invasion. The only part found was the lower jaw with teeth in place (Fig. 1970), this being associated with the bones of

FIG. 1970. — Right lower jaw of the Heidelberg man (*Homo heidelbergensis*), found at Mauer, near Heidelberg. (×⅝.) (After Schoetensack.)

FIG. 1971. — The "dawn-man" (*Eoanthropus*) restored from the skull found at Piltdown, Sussex, England. This "Piltdown man" is the most ancient type in which the size and form of the brain are known; it is estimated that he lived from 100,000 to 300,000 years ago. (After a model by J. H. McGregor. Courtesy of American Museum of Natural History.)

many extinct animals. The jaw shows a combination of human and simian characters, as it is very massive, with retreating chin, giving a projecting or prognathous face, thus much resembling that of a chimpanzee or gorilla, while the upper part resembles that of some large variety of gibbon. The teeth are, however, human, though somewhat primitive, and on this account the relic must be regarded as unquestionably that of a man, though, had the teeth been absent, it would have been impossible to diagnose the jaw as human. The Heidelberg race existed approximately between 200,000 and 350,000 years ago.

The Piltdown Man (Eoanthropus dawsoni) (Fig. 1971). — In 1912 the remains of the third oldest of the known human types were found in the Thames Valley near Piltdown, Sussex, England. These consisted of parts of a much broken skull, a canine tooth, and part of a lower jaw. The skull compares favorably with that of modern man except for the remarkably thick walls, but the tooth and lower jaw are

FIG. 1972. — The original skull of the Neanderthal man found in the Neanderthal (Valley of the Neander) near Düsseldorf, Germany (copied from Alsberg, *Abstimmung des Menschen*).

like those of a chimpanzee. Because these were found separated from the skull, and because of their ape-like character, it is believed by many that the skull and jaw do not belong to the same individual or even the same type, that, in effect, one is human, while the other, the jaw, belonged to an ape. If the skull alone represents the Piltdown man, this will have to be placed in the genus *Homo*, where modern man belongs, but it would still be a distinct species (*Homo dawsoni*). If the jaw also belongs to this type of man, then indeed he was very primitive, and in some respects very similar to his simian relatives. That only the two complementary parts of a head, but belonging to two distinct types, should occur in the same formation, is at least a remarkable coincidence, and until other remains are found, the possibility that they belong to the same individual cannot be denied.

FIG. 1973. — Skull of the "Man of Spy," a member of the Neanderthal race, found in a grotto near Spy, a hamlet near Dinant, Belgium. (Copied from Alsberg, *Abstimmung des Menschen.*)

These remains occur in the deposits of the third interglacial epoch, thus placing the time when the Piltdown race existed, according to Osborn, between 100,000 and 150,000 years ago.

The Neanderthal Man (Homo neanderthalensis) (Figs. 1972–1975). — The remains of this type of man have been known since 1856, when a number of skeletons of this race were found in a cave on the banks of the Düssel River, in that part of its valley known as the Neanderthal, not far from Düsseldorf in Rhenish Prussia (Fig. 1972). Eight years earlier a skull, now regarded as belonging to this race, had been found at Gibraltar, and more recently other similar remains have been found in a number of places in

France and Belgium. Two nearly complete skeletons were found in 1887 in a grotto near Spy (Fig. 1973) not far from Dinant in Belgium, and others nearly as perfect were found near Chareant, France, between 1907 and 1911. An almost complete skull and skeleton were found in a grotto near La Chapelle-aux-Saints at Corrèze, France, in 1908; and the skeleton of a youth was discovered at Le Moustier, France, in 1908, while other skeletons and separated skeletal portions were found in various parts of Dordogne, France, between 1909–1911. Portions of many skeletons of adults and children were also found in 1899 at Krapina, in Croatia, and other remains in Moravia, and on the Island of Jersey in the English Channel.

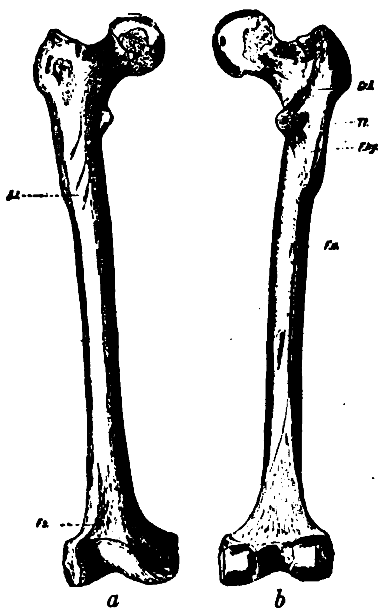


Fig. 1974. — Leg-bones of the Neanderthal man. *a*, Front view; *b*, rear view. One-fifteenth natural size. (Copied from Alsberg, *Abstimmung des Menschen*.)

These remains indicate that the Neanderthal men " . . . were short of stature, but powerfully built, with strong curiously curved thigh bones, the lower ends of which are so fashioned that they must have walked with a bend at the knees. Their long depressed skulls had very strong brow-ridges; their lower jaws, of brutal depth and solidity, sloped away from the teeth downwards and backwards in consequence of the absence of that especially characteristic feature of the higher type of man, the chin protuberance " (Huxley).

These characters gave the Neanderthal skulls a greater resemblance to those of anthropoid apes than to those of modern man, but their brain-capacity was somewhat greater than that of many modern human skulls. In modern man the known range is from 950 to 2020 cubic centimeters, whereas that of the Neanderthal skulls ranges from 1290 in the Gibraltar female, to 1723 c. c. in the man of Spy. However, the actual brain capacity is less significant than the relative development of brain parts, and in those portions which are concerned with the higher processes of the mind, the Neanderthal brain was deficient and showed its nearer relationship to the anthropoids. Many of the body characters, too, suggest those of anthropoids or of new-born infants. In appearance they were very brutish, with a head of enormous size set upon a short, thick trunk in such a way that the head and neck habitually bent forward, forming a continuous curvature with the back. They had short, thick arms and robust legs, the lower part of which, when compared with the upper, were relatively shorter than in modern man. The knees were habitually bent, these men being without the power to straighten the joint to stand fully erect.

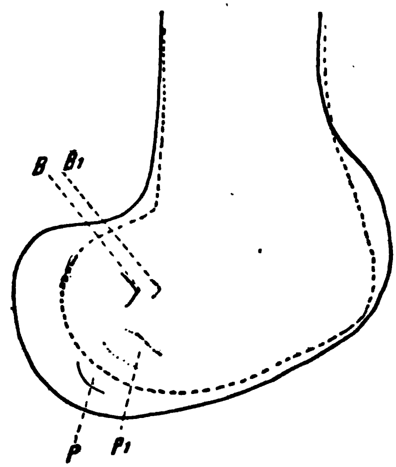


FIG. 1975. — Comparison of outlines of part of the thigh-bone of the Neanderthal man, with that of a modern man. *BB′*, Place of attachment of the ligaments; *PP′*, Location of the sulcus popliteus. (Copied from Alsberg, *Abstimmung des Menschen*.)

This race lived in Europe during the third and fourth interglacial epochs, or approximately between 25,000 and 100,000 years B.C. (Osborn).

Culture Stages and Implements of the Lower Palæolithic

The implements and weapons of the Neanderthal man have been found associated with the skeletons as well as by themselves and indicate that these people possessed a very rude culture, which has been designated that of the Older Stone or Palæolithic age. The implements of the preceding Piltdown race mark the beginning of this industry, but those of the Heidelberg race appear to have been rude stone chips (eoliths), fashioned by nature, while *Pithecanthropus* probably used sticks for weapons. Palæolithic man had acquired the art of chipping his flints and fashioning them for definite uses (Fig. 1976), but he had not arrived at the point where a polish was given to chipped stone, this being a distinctive cultural characteristic of Neolithic man. From the nature and perfection of the chipped implements and from their occurrence at successive levels, the following cultural stages of Palæolithic man have been determined:

1. Pre-Chellean stages, approximately 125,000 to 100,000 B.C.
2. Chellean stage, approximately between 100,000 and 75,000 B.C.
3. Acheulean stage, approximately between 75,000 and 50,000 B.C.
4. Mousterian stage, approximately between 50,000 and 25,000 B.C.

This last was the chief cultural stage of the Neanderthal man, while the others were intermediate between this and the Eolithic type of unmodified stone fragments. The pre-Chellean stage, the period of the Piltdown man, witnessed the earliest and crudest attempt at fashioning stones for various purposes.

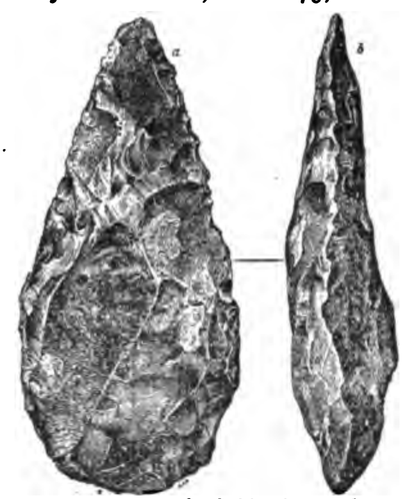


FIG. 1976. — Palæolithic flint implement of spear-head shape, from Pleistocene gravels at St. Acheul, near Amiens, in the valley of the Somme, France. *a*, Side view; *b*, same seen edgewise. (× ½.) (After Lyell, *The Antiquity of Man.*)

During the Chellean and early Acheulean stages, man lived mostly in the open, this being permitted by the mild climate of the interglacial epochs. With the advent of the colder climatic conditions of the fourth or Würm glacial stages, however, he was forced to seek shelter in caves and grottos, and rude clothing had to be manufactured. For this purpose special implements had to be devised, while the change in the character of the implements of chase and war indicate that the race had declined somewhat in muscular strength and vigor with this change toward less hospitable conditions on the part of nature. This was the period of the Mousterian culture of the Neanderthal.

Burial Customs of the Neanderthal Race

From the manner in which the skeletons of these ancient men were placed, it appears that special attention was being given to the burial of their dead by the Neanderthal men. Moreover, from the fact that ornaments and flint implements were buried with the dead, it has been argued that the Neanderthal men had developed an instinctive belief in immortality or in a continuance of life under new, though similar, conditions in some other sphere of existence.

Apparently descended from the Heidelberg race, the Neanderthals seem to have been a race which specialized along certain lines, and after a long period of dominance wholly disappeared by extinction. Some authorities, however, have suggested the possibility that some of the lowest races of modern man might be the lineal descendants of the Neanderthals.

Races of the Later Palæolithic Age

The Crô-Magnon, Aurignacian and Grimaldi Races. — In 1868 five human skeletons, representing an old man, two young men, a woman, and a child, were found in a buried grotto near the little hamlet of Crô-Magnon on the Vézère River in France. These proved to be representative of a distinct race of human beings and the most typical of the newer Palæolithic races. Sometime before this discovery, a painted skeleton, which later proved to be of this race, was found in the "kitchen-middens," or refuse heaps, on the floor of Paviland Cave, a grotto in the face of a steep limestone cliff on the coast of Gower, Wales. Another grotto, at Aurignac, in the province of Haute-Garonne, southern France, discovered in 1852, was nearly filled with bones, representing 17 individuals which, though they were reinterred in the cemetery of Aurignac, and so lost to science, are believed, on the evidence of the associated implements, which are like those found with the Crô-Magnon skeletons elsewhere, to have been the remains of men of this race. From this occurrence the Aurignacian culture stage of the Newer Palæolithic period has been named. It should, however, be noted that a skeleton of a more primitive type of man was found associated with the oldest of the Aurignacian implements at Combe Capelle, Dordogne, France, in 1909, and this has led to the belief that another race, the Aurignacian (*Homo sapiens* var. *aurignacensis*) preceded the Crô-Magnon in Europe.

Skeletons of the Crô-Magnon, fourteen in number, have also been found in the famous Grimaldi "Grottos," situated in the limestone cliff which terminates the southern spur of the Alps at the point now marked by the Franco-Italian boundary on the Mediterranean coast, and a short distance east of the city of Mentone, France. This region became noted when, in 1872,

FIG. 1977. — A family of the Crô-Magnon race as it probably appeared in its primitive home. From a painting made by Charles R. Knight under the direction of Professor Henry F. Osborn. (Courtesy of American Museum of Natural History.)

the skeleton of the "Man of Mentone." was found in one of these grottos. Beneath the burial place of the Crô-Magnon skeletons in these caves were found in 1906 the skeletons of a youth and of a woman, representing a shorter-statured negroid race of distinct type, to which the name *Grimaldi race* has been applied. In their tooth structure, these Grimaldians show a greater resemblance to the anthropoid apes than do the Neanderthals. They had, moreover, long forearms, curved thigh bones, and strongly projecting teeth (prognathism). In cranial capacity, however, they approached the man of Spy. This race has been regarded as an intermediate step in the evolution of the white and black races, being possibly an ancestor of both, though it has also been thought to represent a distinct branch of the genus *Homo*.

The Crô-Magnons were widely distributed over Europe, living in France, Spain, Austria, and extending westward to Wales. Their remains have also been found in Syria, and will probably be discovered elsewhere in Asia, which was apparently their ancestral home. All the remains are associated with implements of the Aurignacian or later culture stages.

This was a tall race, the men ranging from 5 feet 10½ inches to 6 feet 4½ inches in height, while the women were but little shorter (Fig. 1977). The skull is of the long-headed type (dolichocephalic) with very high forehead, broad face, broad and high cheek bones, much reduced eyebrow-ridges, strong jaw, and massive, prominent chin. Their brain capacity was surprisingly high, that of the woman of Crô-Magnon exceeding that of the average male of to-day. The leg was very long, compared with the arm, while the forearm and shin-bone showed remarkable lengthening when compared with the upper arm and thigh bone, respectively. These men were swift-footed and powerful hunters, and the race has been called one of the finest the earth has ever supported. From them probably descended several of the modern Asiatic tribes, which still show some of their characteristics.

These men, too, revered their dead, burying them by preference in caves, with folded arms and with the head surrounded by necklaces of perforated shells, while flint implements were placed beside the bodies. Coloring of the body, either for preservation or ornament, was widely practiced, this color being commonly seen in the skeletons.

Culture-Stages of the Later Palæolithic

The following culture stages have been recognized for the Upper Palæolithic:

5. Aurignacian.
6. Solutrean.
7. Magdalenian.
8. Azilian-Tardenoisian.

Of these the Aurignacian and Magdalenian were the typical culture stages of the Crô-Magnons. The Solutrean culture was introduced by the Brünn Race and the Azilian-Tardenoisian by the Grenelle and other races. These culture stages all belong to late glacial or post-glacial time, following the fourth or Würm period of glaciation.

The Aurignacian Culture Stage. — The industry and culture of these men have been found distributed around the entire periphery of the Mediterranean, occurring in northern Africa, Sicily, and the Italian and Iberian peninsulas. They were in part derived from, but an improvement upon, the Mousterian culture, the implements, as in that stage, being retouched on one side only, the other retaining its natural character. Bone implements were now added to those of stone, including the bone awl and javelin point. Most characteristic is the development of graving tools, for these people had developed the art of engraving and sculpture as well as that of painting in color. They carved their implements and their articles of ornament and they decorated the walls of their caves with engravings and paintings of animals, such as the horse, ibex, reindeer, woolly rhinoceros, cave-bear, and mammoth, and carved human statuettes in bone, ivory, and soft stone.

The Brünn Race and Solutrean Culture. — This was a contemporary race of the Crô-Magnons, living mainly in eastern Europe and, unlike the latter, which appears to have been primarily cave-dwelling, living largely in the open. Remains of this race were found in 1891 in the loess of Brünn, Moravia, where they were associated with the bones of the woolly mammoth and other animals of the period. A skull, apparently of a member of this race, had been found at Brux, in Bohemia, in 1871, and portions of 20 skeletons in the loess at Předmost, Moravia, in 1880 and later, while in 1888 a skull, believed by many to belong to this race, was discovered in the gravel of the Thames Valley at Galley Hill, England.

The skulls of these humans are very elongate and of a relatively low character, with retreating forehead, but with prominent chin. They lack the strong cheek-bones of the Crô-Magnon, their faces being of the narrow, modern type, but not very long. On the whole, they were a much inferior race in structure and brain development.

Their implements have been found as far west as south central

France, where a great open air camp existed at Solutré, near the Saône River, from which locality the culture stage has derived its name. The flints are an improvement over those of the other races, in that they were chipped by pressure instead of blows, and over the entire surface of the stone instead of one side only. Moreover, these implements were given a fine sharp edge and a perfect symmetry.

The Solutrean culture was the successor of that of the Aurignacian stage, being apparently adopted by the Crô-Magnons of western Europe. This epoch also witnessed a decline in art, which was perhaps due to the open-air life which was adopted at this

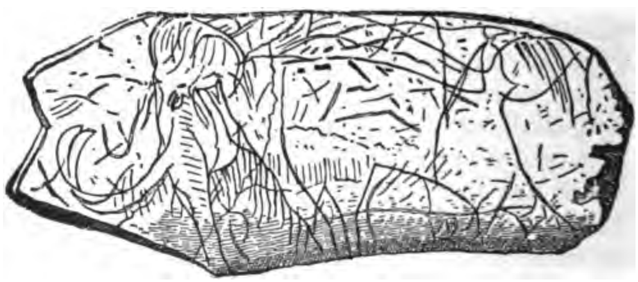


Fig. 1978. — Drawing of the mammoth on ivory by a prehistoric French artist. (After Lucas, from Matthew.)

time. The fashioning of perfect instruments for the chase seems to have chiefly occupied the craftsman's attention.

The Magdalenian Culture Stage. — This stage is named from the great rock shelter of La Madeleine in the heart of the Dordogne district, France, on the right bank of the Vézère River. This epoch witnessed the highest artistic and cultural development of the Crô-Magnons and appears to have been coincident with the return of a colder climate and a southward migration of the northern types of plants and animals. The men of this period again took to dwelling in caverns, where the art of mural painting was revived, while at the same time the flint industry deteriorated. The finely finished flints of the Solutreans were replaced by flakes and splinters of poor workmanship, and the beautiful laurel leaf spearhead and the shoulder dart, so characteristic of the preceding epoch, disappeared entirely. In their stead many small implements for graving and carving bone were made. Bone-implements, on the other hand, became very characteristic of this period, and they were commonly ornamented by carvings (Fig. 1978). Bone needles with pierced ends also appeared, as the need for clothing became manifest with the increasing rigor of the climate.

While the carving or ornamentation upon the bone-implements and the fashioning of statuettes was highly developed, the revival of mural painting was perhaps the most distinctive artistic advance made by the Magdalenians. As in the earlier stage, contemporary

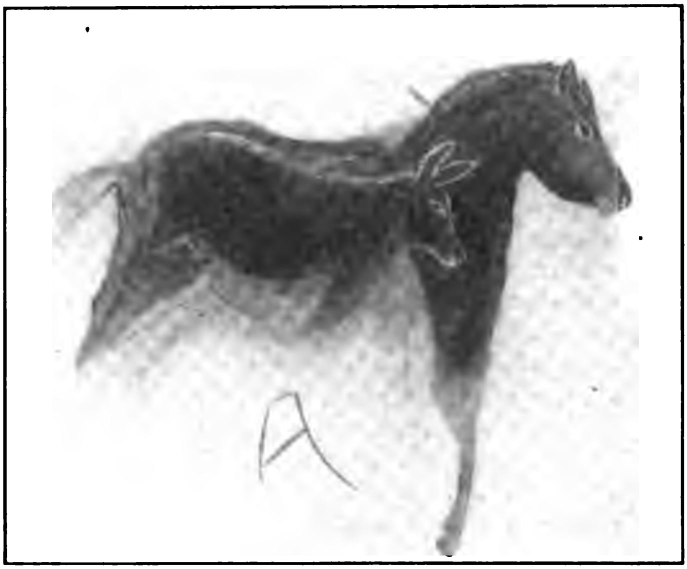


FIG. 1979. — Painting of the desert or Celtic horse on the ceiling of Altamira, in northern Spain. The eye, ear, chin, mouth, and nostrils are engraved, while the entire painting is colored in red ochre with black manganese outlines. The long slender limbs, delicate head, and short body are clearly depicted. The figure of a hind is painted over it. (Courtesy of the American Museum of Natural History.)

animals formed the chief objects portrayed, and these were not only painted in colors, but the outlines and many details were often engraved upon the stone (Fig. 1979).

Toward the close of Magdalenian time, art once more declined, and instead of the representation of animal and human figures, schematic designs and conventional figures were chosen as subjects by the artist. These became characteristic of the succeeding stage.

Grenelle and Other Races, and Azilian-Tardenoisian Culture Stage. — This is the last of the Palæolithic stages and marks the invasion of western Europe by new races. The Crô-Magnon race declined, but apparently never became wholly extinct, their descendants probably living in the Dordogne and other districts of France to-day. The new invading races were:

(1) The *Furfooz-Grenelle* or *Alpine* race, extremely broad-headed, occupying the Danube Valley, eastern Bavaria, and extending northward into Belgium. This race was probably of Asiatic origin and brought the Azilian culture, without art or developed flint industry.

(2) The *Tardenoisian* or *South Mediterranean* race, which occupied north Africa and extended into Spain. This race is known only by its culture, chiefly expressed in the extremely small flint tools and weapons, and conventional or schematic pictorial designs which have been regarded by some as marking the beginning of written language. Remains of long-headed, narrow-faced men found in eastern Bavaria may represent this race.

(3) The *Maglemose* or *Northern* (Teutonic) race, also known only from its implements, which include horn and bone harpoons, fish-hooks, chisels, awls, spear-points, and smoothers, but few flints. These men apparently domesticated the dog, and they had a crude art similar to that of the early Aurignacian epoch, but probably of independent origin. The type region is in Denmark, where these people dwelt on the borders of fresh-water lakes into which their implements were dropped probably from rafts which served as dwelling places.

The Neolithic Age

The men of the Old Stone Age were eventually replaced by, and became fused with, the men of the Newer Stone Age, the *Neoliths*, which have developed the art of polishing their implements. These, like Palæolithic man, originated in Asia and migrated into Europe, bringing with them the higher culture which they had developed, including the art of pottery-making, and a knowledge of the rudiments of agriculture. These men gave up the nomadic life, and settled in permanent communities in which agricultural pursuits took a leading place, while the domestication of wild animals and plants was undertaken.

This age began in Europe between 7000 and 10,000 years ago, but much earlier in Asia.

The Age of Copper, Bronze, and Iron

The use of copper for implements and ornaments was discovered in Egypt about 5000 or 6000 years ago, and this was succeeded 1500 years later by the invention of bronze, an alloy more durable than the pure copper metal. Finally, the melting of iron was discovered, probably by accidental melting of iron-ore by a long-continued camp fire over its outcrops or among scattered fragments, and the age of iron began. This was perhaps 3200 years

FIG. 1980. — The late Professor Eduard Suess, who in his great work, "The Face of the Earth," has summarized the existing knowledge on the form, structure, and development of the crust of our Earth.

ago. The use of coal for fuel began in the 15th century A.D. in England, and this laid the foundation for the development of steam and electricity.

Man in America

At present there is no evidence that palæolithic man came to America, for all the human remains so far found are clearly referable to the North American Indian. Man existed here, according to the best available evidence, as the contemporary of the mastodon, the extinct bison, and the ground-sloth (*Megalonyx*). In point of culture, however, the American Indian represents all stages from the palæolithic to the most highly developed neolithic type, according to the climatic and other physical conditions of the regions occupied by the various tribes. The American aborigines appear to have come from Asia by way of Behring Strait and Alaska, probably toward the close of the glacial period, there being at present no evidence of the existence here of men during the Pleistocene. But while these men developed a high degree of culture of their own, civilization, as we know it, arose in the Old World, in Asia and North Africa, where the effect of glaciation was less marked than in Europe, but where the stimulus of a bracing climate, induced by the lingering effects of the glacial period, urged men to activity, and developed mental alertness and energy which enabled their possessors to recognize the value of chance discoveries, and to develop them, first for their own advantage, and later for the benefit of their community.

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